706

WAYNE KERR

AUTOBALANCE PRECISION BRIDGE

B331

Maintenance Manual

MP MASTER

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AUTOBALANCE PRECISION BRIDGE

B331

Maintenance Manual

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AUTOBALANCE PRECISION BRIDGE

B331

Maintenance Manual - Part 1

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INTRODUCTION

The physical description, specification and use of the B331 are dealt with in the Operating Instructions supplied with the instrument. This manual contains all the necessary information for those users who require a detailed knowledge of the circuits used, their operation and adjustment.

The book is divided into two parts, the first of which contains a complete technical description of the instrument together with a block diagram, all circuit diagrams and, where it is felt to be beneficial, simplified circuit diagrams of the various sub-assemblies.

The second part of the book deals with the setting-up and maintenance procedures necessary to keep the instrument in good order. Complete instructions are given for the adjustment of all preset controls and also for the replacement of the digital indicator tubes. In preparing these instructions, the use of any special test equipment has been avoided. Finally, a complete list of electronic components is given.

The Autobalance Precision Bridge B331 uses the transformer ratio-arm principle. A complete analysis of this type of bridge is given in the Wayne Kerr Monograph No. 1, 'The Transformer Ratio-Arm Bridge'. An analysis of the self-balancing principles used in this instrument is given in Electronic Engineering Vol. 35, No. 430, December 1963, 'Self-Balancing Transformer Ratio-Arm Bridges'. Copies of the Monograph and reprints of the article are available on request.

NOTE: The main body of the text deals with instruments up to Serial Number 125, at which point several changes, chiefly mechanical, were introduced. These changes, together with appropriate illustrations, are given in Appendix 1.

FUNCTIONAL DESCRIPTION

Summary

1. The B331 comprises a bridge nucleus, a 1592Hz oscillator*, a lead eliminator, a feedback amplifier, a 90° phase changer, two phase-sensitive detectors - one for capacitance and one for conductance, a base drive amplifier, meter circuits, digital indicator units and a power supply unit. These circuits are linked together as shown in the block diagram fig. 2.

2. A standard voltage derived from a Wien bridge oscillator is applied to the component under test and the resulting current is fed via a current transformer to the feedback amplifier. A current from the feedback amplifier output is fed back to another winding on the current transformer in such a direction as to cancel the flux produced by the original current. Ideally, the system would indicate a true balance when these currents were exactly equal. However, since this would remove the feedback amplifier input signal, the balance indication falls short of this ideal condition by an amount which can be predetermined according to the required accuracy of the bridge. The approach to the ideal condition is governed only by the gain of the feedback amplifier, which can be made as large as necessary. This is shown diagrammatically in fig. 1.

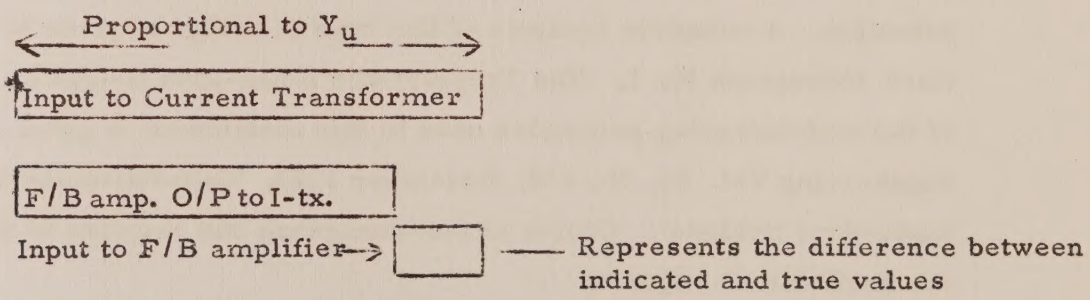
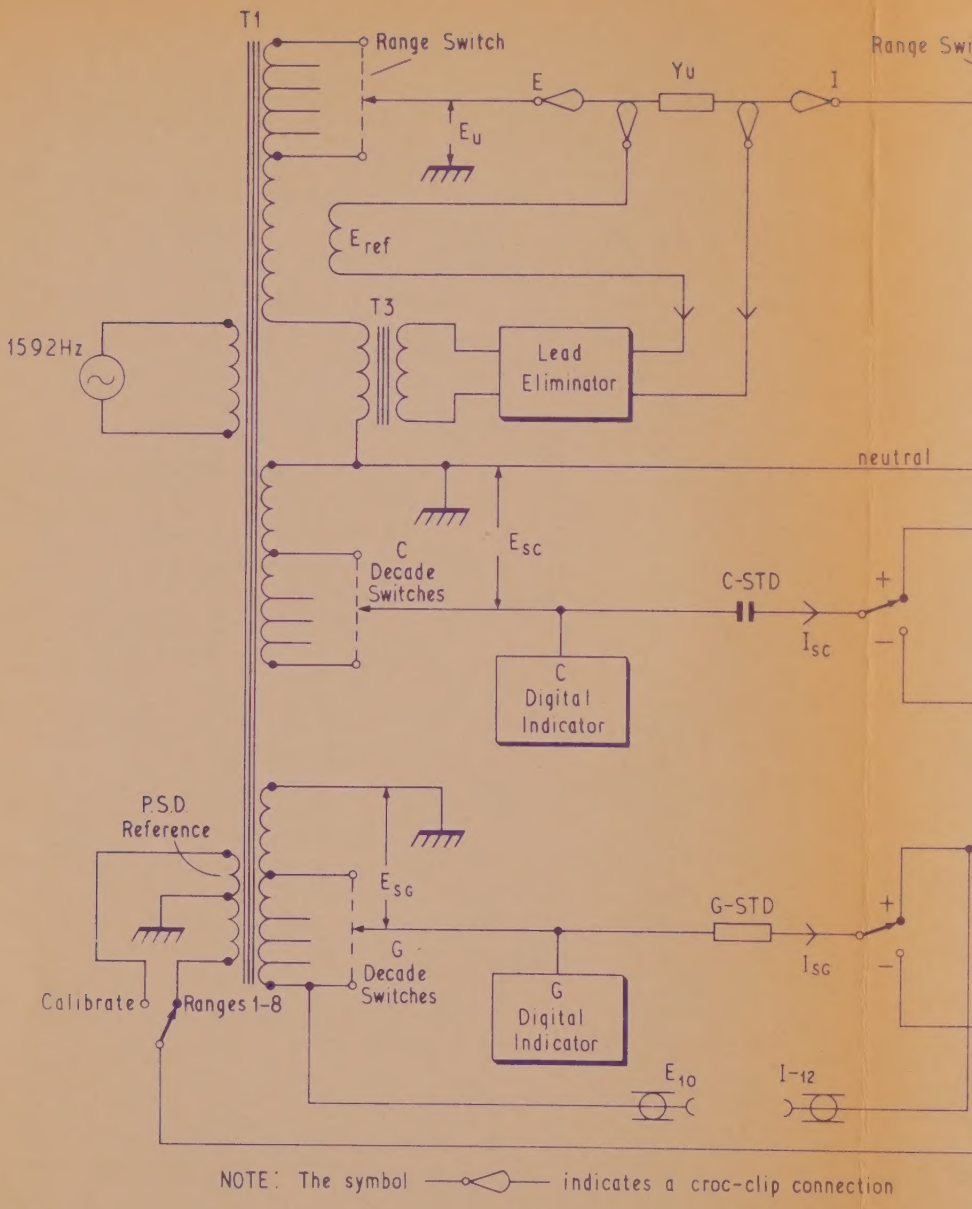

Proportional to Y_u
Input to Current Transformer
F/B amp. O/P to I-tx.
Input to F/B amplifier
Represents the difference between indicated and true values

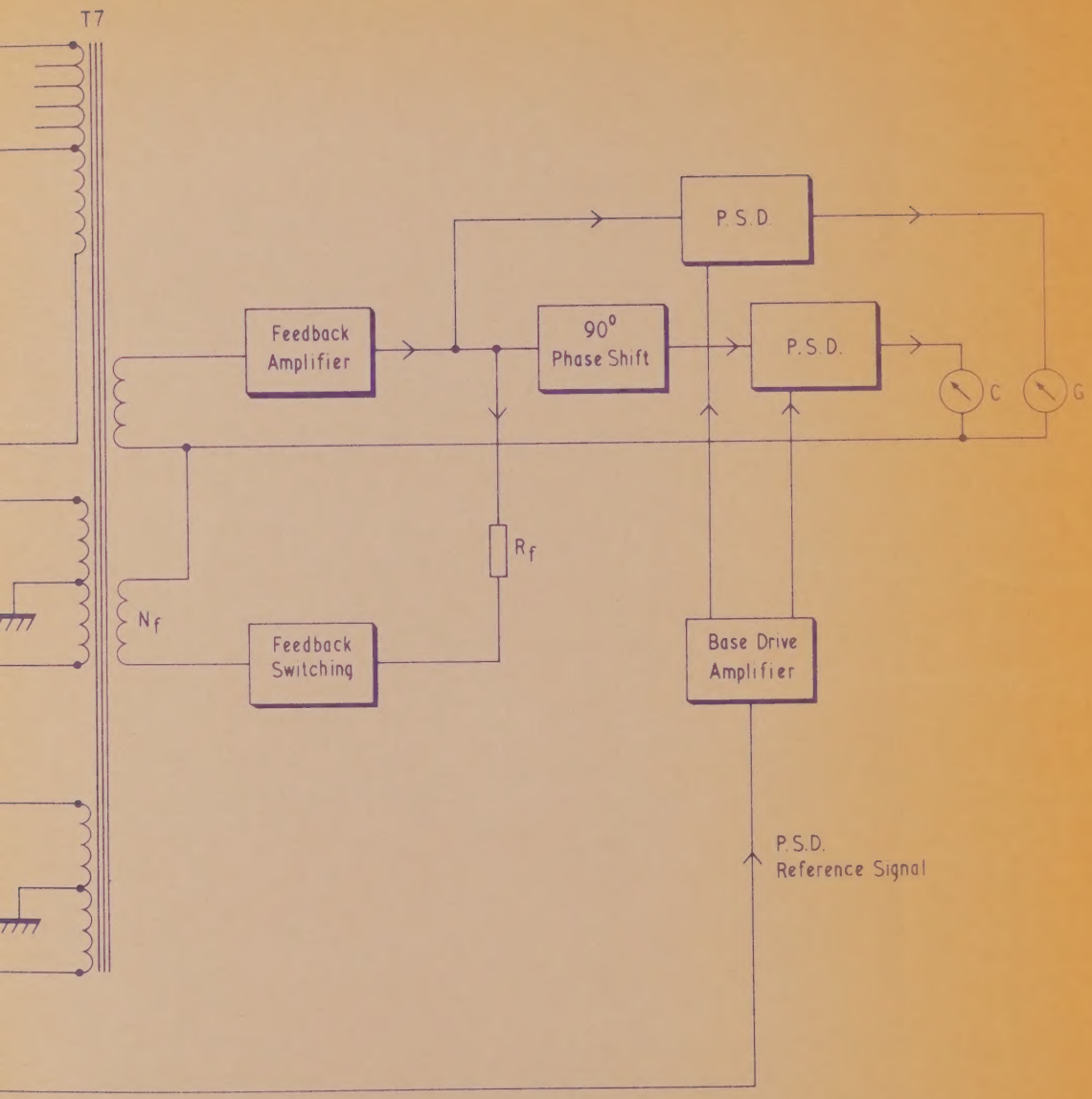
Fig. 1. Basic Approach to Autobalance.

3. It can be shown that the feedback amplifier output has components that are directly proportional to the capacitance and conductance of the component under test or, as the decades are brought into use, they are proportional to the

* A 1kHz oscillator can be fitted to order. Throughout this manual the standard frequency of 1592Hz is assumed. Differences in description or procedures arising from the use of the alternative frequency are noted where applicable. The components list gives values for both frequencies.



NOTE: The symbol —⋈— indicates a croc-clip connection



B331 Block Schematic Diagram Fig. 2

difference between the decade setting and the value of the test component. The components of the output signal are then separated so as to operate the C and G meters simultaneously.

The Bridge

4. Preliminary Balance This condition results immediately on connection of the unknown admittance Y_u (assuming correct range selection) and before the operation of any of the decades. Referring to fig. 2 (and ignoring the lead eliminator for the moment), the voltage transformer T1 has a winding, tapped at several points, which produces a voltage E_u. This voltage is applied to one side of the unknown Y_u and causes a current I_u to flow through Y_u to a winding on the current transformer T7. This winding is also tapped at points equivalent to those on T1, the taps on both transformers being selected by means of the Range switch.

5. The flux in T7 causes an input signal to be fed to the feedback amplifier. A current proportional to the amplifier output E_f is fed back via the feedback resistor R_f to N_f turns on T7 wound in such a direction as to oppose the original flux. Since, at this stage in the measurement, the decades are not in use, the net flux in T7 is that produced by the difference between I_u and I_f (the feedback current) at the end of the preliminary balance, i. e., before the decades are introduced. The gain of the feedback amplifier is such that this flux can be assumed to be zero and therefore the feedback amplifier output is directly proportional to Y_u.

6. The feedback amplifier output has in-phase and quadrature components that are respectively proportional to the conductance and capacitance of the test component. The output signal is fed directly to the phase-sensitive detector associated with the conductance meter. The signal is also fed to a 90° phase shift amplifier whose closed loop gain is unity. The output from this amplifier is taken to the phase-sensitive detector associated with the capacitance meter. This arrangement gives an aperiodic indication of capacitance and thus does not depend on the oscillator frequency for accuracy.

7. Both detectors have a reference signal that is derived from the oscillator via a winding on the voltage transformer. Because the reference signal

has a sinusoidal waveform it is not suitable to act as a switching waveform, but is used instead to drive a squarewave generator. This circuit is referred to as the Base Drive Amplifier because of its application; it has four outputs, one for each transistor in the two phase-sensitive detectors. The detectors operate the C and G meters via the appropriate polarity switches.

8. Precise Balance The voltage transformer T1 has other multi-tapped windings that provide the voltages E_{sc} and E_{sg}, which are applied to the bridge standards. For simplicity, these are shown on fig. 2 as single windings. The voltages E_{sc} and E_{sg}, which are applied to the C and G standards as soon as the first, or most significant C and G decades are operated, produce the currents I_{sc} and I_{sg} respectively. Since the value of both E_{sc} and E_{sg} is selected - by means of the appropriate decade buttons - to correspond with the first digit of the initial meter indication, the resulting currents, when fed to windings on the current transformer T7, partially balance the bridge to the extent represented by these first digits. The residual out-of-balance is then dealt with as before by the feedback amplifier and meter circuits. However, the meters would not give a very useful indication unless a corresponding increase were made in the detector sensitivity. By making this increase in sensitivity equal to ten times, the new meter indications give the second and third significant figures. Similarly, when the second order decades are operated to transfer the first digits of the new meter indications to the second order indicators, a simultaneous ten-times increase in detector sensitivity again takes place so that the meters then indicate the third and four th significant figures. When the process is repeated with the third order decades, a 5-figure readout (or 6-figure readout at full range capability) is attained at the full 0.01% accuracy of the system.

9. Both of the 'standards' windings on T7 have a centre-tap, which is connected to neutral; the currents I_{sc} and I_{sg} are fed to one or the other of their respective outers via the C and G polarity switches so that the flux change in T7 can be either additive or subtractive according to the required polarity. Connections from the G windings on both voltage and current transformers are brought out to side panel sockets E_{10} and I_{-12} for the connection of external standards. The various uses of these sockets are explained in the Operating Instructions handbook.

Lead Eliminator

10. On ranges 2, 3 and 4, the internal impedance (i. e. the impedance of the transformer windings, connecting leads and switch contacts) would be sufficiently large to make a significant difference between the true and indicated values of the unknown admittance were it not for the presence of the 'lead eliminator'. This error is caused by the passage of the current drawn from the voltage transformer by the unknown through the leads and switches etc. The lead eliminator circuit senses the voltage actually applied to the unknown and compares this with a reference voltage E_{ref}; the difference is then fed to a feedback amplifier so as to derive a correcting voltage, which is added in series (via T3) with the main voltage winding on T1. The reference voltage is obtained from a winding on the voltage transformer that is similar to the E_u winding but, because the reference winding is at all times unloaded, its voltage remains accurate.

11. As with any feedback system, the correction falls short of perfection by the amount necessary to drive it, and is therefore a function of the gain of the lead eliminator amplifier. In practice, the internal impedance is reduced by approximately one-hundred times.

Low Impedance Measurements

12. When it is required to measure impedance values below 10Ω, the method of measurement described in the previous paragraphs becomes impracticable owing to the uncertainty of lead and contact resistances. For the precise measurement of such low impedances a different technique is adopted.

13. In the bridge arrangement as previously considered, a standard voltage is applied to the unknown and the resulting current is compared with that in a standard impedance. For low values of unknown impedance, i. e. when the Range switch is set to 1 (Low Impedance), the bridge configuration is rearranged so that Y_u is the shunt element in a T-network (see fig. 3). If the series elements are made sufficiently large compared with the unknown, the source side of the bridge can be considered as a constant current generator while the detector side functions as a voltmeter. This technique is analysed in Wayne Kerr

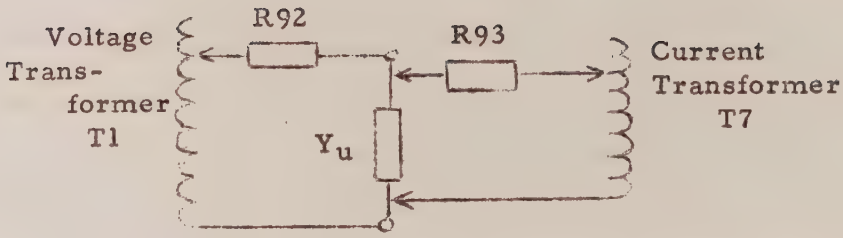


Fig. 3. Low Impedance Measurement

Monograph No. 1. In practice, the series elements (R92 and R93) are made 100 times greater than the range maximum. This factor would normally give rise to a systematic error of 2% (explained in para. 33) but the lead eliminator is rearranged to reduce this error to negligible proportions so that the maximum accuracy on this range becomes 0.2%, this being the combined tolerance of R92 and R93. This rearrangement is made possible because the lead eliminator would otherwise be redundant on Range 1 since the system of measurement requires a four-terminal connection.

Calibrate Facility

14. The internal standards of the instrument are used to calibrate the bridge meter circuits before making actual measurements. In normal use, current from the 'standard' side of the bridge is fed to the current transformer to balance the current (or a portion of it) from the 'unknown' side. If current from the 'standard' side is fed to the transformer in the absence of any 'unknown' current (as, for instance, during calibration) the meter circuits would indicate in a negative direction. This is overcome by arranging that the Facility switch, when set to Calibrate, reverses the phase of the reference voltage fed from the voltage transformer to the Base Drive Amplifier. The internal standards, in conjunction with the decade switches, can then be used to set up a standard indication on the C and G meters, the main feedback network being then adjusted to correct the meter indications as necessary.

Measurements Affected by Change of Frequency

15. Since the bridge uses a capacitance standard for the measurement of admittance, any measurements on inductors (made on the normal ranges) must be frequency dependent. On the Low Impedance range (Range 1), owing

to the effective reversal of the method of measurement (see para. 12 and 13) whereby the bridge measures equivalent series components instead of equivalent parallel components, it is the capacitance measurements that are frequency conscious.

16. The bridge standards and the transformers are so arranged that, at the design frequency, the range coverage follows logically to the next decade when changing from Range 2 to Range 1, that is, from a parallel to a series type of measurement. At other frequencies, however, the range coverage is not sequential owing to the presence of the term ω (=$2\pi f$) in the denominator of the expression for L on Range 2 and C on Range 1. The effect of this is to cause a range overlap as the frequency increases and a gap as the frequency decreases. The extent of the gap at different frequencies is shown by means of a graph in the 'Operating Instructions', which also gives alternative methods for use under these conditions.

MECHANICAL DESCRIPTION

General Construction

17. The various sub-units of the instrument are disposed round five sides of the assembly, including the front panel. The bottom tray of the assembly is secured to the front panel, but the remaining two side panels and the top panel are hinged. Thus, by swinging these three panels outwards, the interior of the instrument is completely exposed for maintenance purposes.

18. The Bridge nucleus is located in the fixed bottom tray of the assembly. This sub-unit contains all the transformers except T4, T8 and the power transformer T9. Also located in the nucleus unit are nine sections of the Range switch S2; two of the sections (S2/1 and S2/6) each comprise two wafers in order to accommodate the width of some of the tape conductors from the voltage and current transformers. Two other sections of S2 (S2/8 and S2/19) are associated with the Lead Eliminator circuit. The part of the Range switch that is located in the nucleus is driven from the main part of S2 by means of a pair of gear pulleys and a plastic toothed belt. The shaft of the main part of S2 also carries a cam, which operates the power supply on/off switch.

19. There are five main printed circuit boards as follows.

(a) The feedback amplifier and 90° phase shifter; this is the largest board and is mounted on the top hinged panel. This board carries a small subsidiary printed circuit board on which is mounted a band-pass filter; the purpose of this is explained in para. 46. On later models the filter is incorporated in the amplifier p-c board.

(b) The oscillator; this p-c board is mounted on one side of the nucleus sub-unit.

(c) The lead eliminator amplifier, mounted on the other side of the nucleus sub-unit.

(d) The C and G phase sensitive detectors and the base-drive amplifier; this is the H-shaped board mounted on the side of the range indicator lamp assemblies.

(e) The power supply p-c board; mounted on the right-hand hinged side panel (as viewed from the front).

There are also a number of minor p-c boards that carry the decade indicator tubes and some of their associated components.

Film Wiring

20. The greater part of the circuits associated with the decade switches and the range indicator lamps are connected by means of film wiring. This consists of thin film copper tape (similar to that on normal printed circuit boards) sandwiched between two sheets of a flexible plastic material.

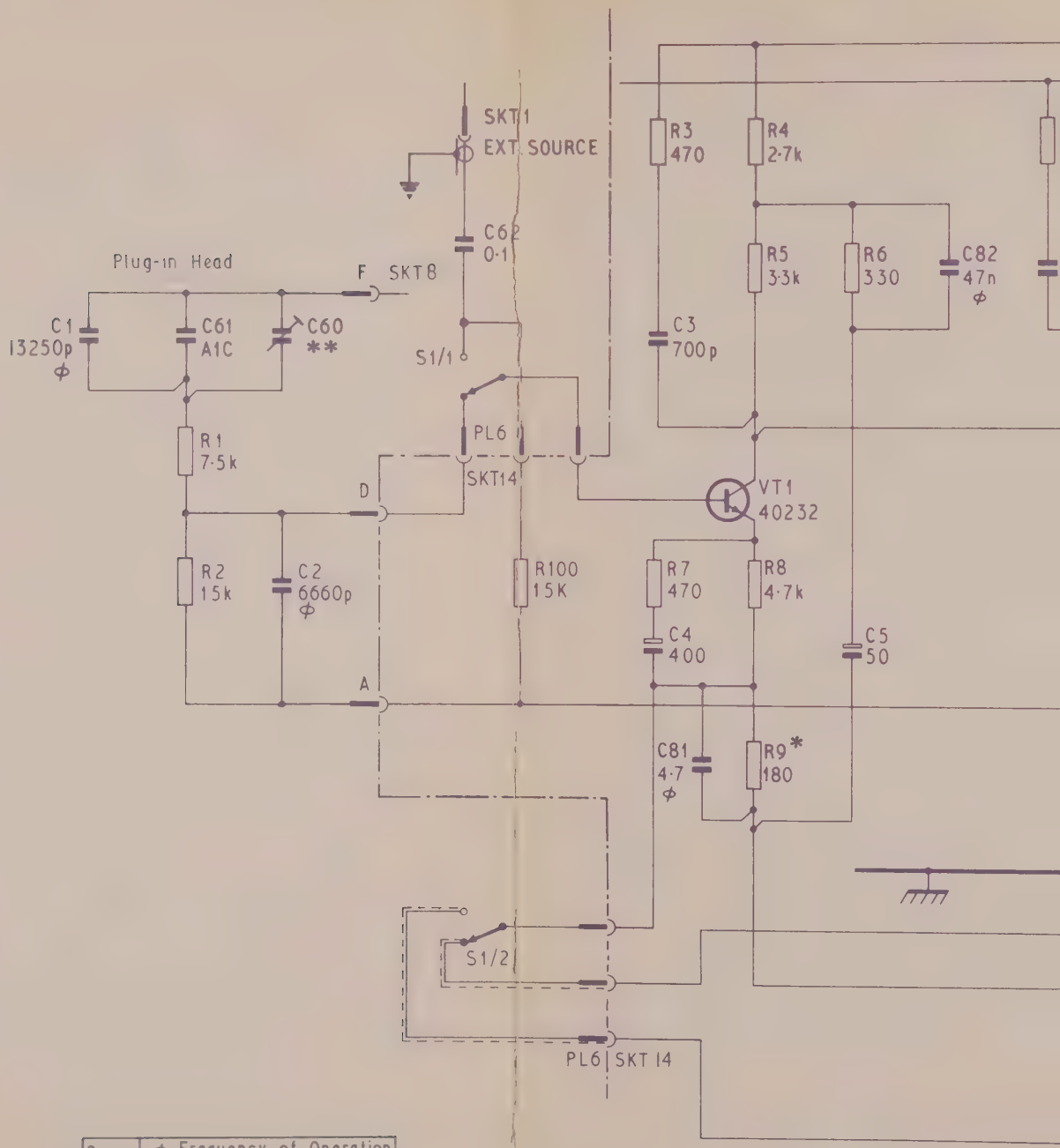
Range Multiplier Lamps

21. The capacitance and conductance range multiplier indicators are two similar assemblies each of which comprises twelve indicator lamps and an optical system. The light from the selected lamp passes through a plastic condensing lens in front of which is a mask carrying the twelve symbols. A light trap prevents stray light from passing through any but the selected image. The light beam then passes through a projection lens - also plastic - and a further light trap to the Perspex viewing screen. Apart from the lamp block, which can be withdrawn for replacement of the lamps,* the unit is a sealed assembly.

* see Operating Instruction book

| | | |

R		1,2			100	3,7	4,5,8,9	6			12
C	1	61	60,2	62		3,4,81		5	82		8
Misc				S1/1 S1/2			VT1				



Comp. Ref.	φ Frequency of Operation		
	1,000 Hz	1592 Hz	
C1	21,000p	13,250p	
C2	10,660p	6660p	
C81	10n	4·7n	
C82	N.R.	47n	
C83	33n	N.R.	

* R9 is a Silistor

** Either C60 or RV18 or b

| | | |

Oscillator

22. A simplified circuit diagram of the oscillator is given in Fig. 4a and the complete circuit diagram in Fig. 4b. The circuit is essentially that of a Wien Bridge oscillator in which the four arms of the bridge network are R1/C1, R2/C2, thermistor TH1 and silistor R9. Overall feedback is taken from the feedback winding on T1 and the values of the Wien bridge network components are such that the feedback is in phase at 1592Hz* so causing the circuit to oscillate at that frequency. The frequency determining components are mounted on a plug-in head shown in Fig. 25.

23. Thermistor TH1 prevents variation in the oscillator output should changes occur in the load or supply voltage. However, since TH1 cannot differentiate between an incipient change in output level and a change in ambient temperature, the temperature-sensitive element ('Silistor') R9 is included in the Wien bridge network.

24. Transistors VT1 and VT2, which form the high gain amplifier, are connected as a d. c. feedback pair to give improved stability over the operating temperature range. Transistors VT3 and VT4 are a long-tailed pair output stage. The emitter circuit of the long-tailed pair incorporates a constant current generator, VT26.

25. Initially, the collector of VT1 and the base of VT2 are at the supply potential and VT2 conducts. The potential at the emitter of VT2 is divided by the potential divider R10/R11. The voltage at the junction of R10/R11 is fed back via R2 to the base of VT1, so causing VT1 to conduct. VT2 base and, hence, emitter potential is reduced and this, in turn, reduces the potential at VT1 base. Negative feedback, moderated by R6/C5, is applied to VT1 collector circuit by returning R4 to the collector of VT4.

26. The system is stabilised at a level determined by the feedback tapping point on VT2 emitter. The d. c. feedback to VT1 base greatly reduces the tendency of the base/emitter potential to drift with temperature variation; this ensures that the operating point for VT2 collector is reasonably constant. Capacitors C6/C7 prevent feedback at the operating frequency.

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* or 1kHz if appropriate

27. The output from the d. c. feedback pair is taken from the collector of VT2 via the phase-correcting coupling network R14, C38, C39 to the oscillator output stage. This comprises the long-tailed pair VT3 and VT4 in whose collector circuit is the centre-tapped primary winding of the voltage transformer T1. The transistor VT26 in the emitter circuit of VT3/VT4 gives the effect of a high impedance without the necessity for a high voltage h. t. line.

28. When the instrument is used with an external source and detector, the Wien bridge network is disconnected from the base of VT1 by means of switch S1/1. The external signal then passes via SKT1, C62, S1/1, PL6 and SKT14 to the base of VT1. Transistors VT1 to VT4 and VT26 amplify the signal as described in the previous paragraphs. When switch S1 is set for operation from an external source, S1/2 connects R155 in place of thermistor TH1 in the feedback path, thus preventing damage to the thermistor should an excessive signal be applied at SKT1. In normal use, the oscillator output is such as to produce a peak-to-peak voltage in T1 of approximately 50mV per turn; when an external source is used, the input level should be adjusted so as to approximate this condition. Potentiometer RV18* gives a small degree of frequency adjustment.

Bridge Nucleus

29. The contents of the Bridge nucleus were given in para. 18; the circuit diagram is given in Fig. 5. From this it will be seen that the tappings on the range winding of T1 are arranged in multiples of 3 and 10 while those on the range winding of T7 are in multiples of 4 and 12. This arrangement keeps the turns on each side of the bridge more nearly balanced than would be the case if the windings were tapped in orders of ten - when the E and I windings would be either equal or ten times different on successive ranges.

30. The maximum number of turns on the E and I range windings (T1 and T7) compatible with the attendant losses and required accuracy are 300 and 400 respectively. This criterion makes it necessary to use the auto transformers T2 and T6 to obtain the range tappings for Ranges 2 and 3 since it is impossible to produce fractional turns. Thus the tappings on T2 are equivalent to tappings of 1 turn and 0.3 turn on T1 while those on T6 are equivalent to tappings of 1.2 turns and 0.4 turn on T7.

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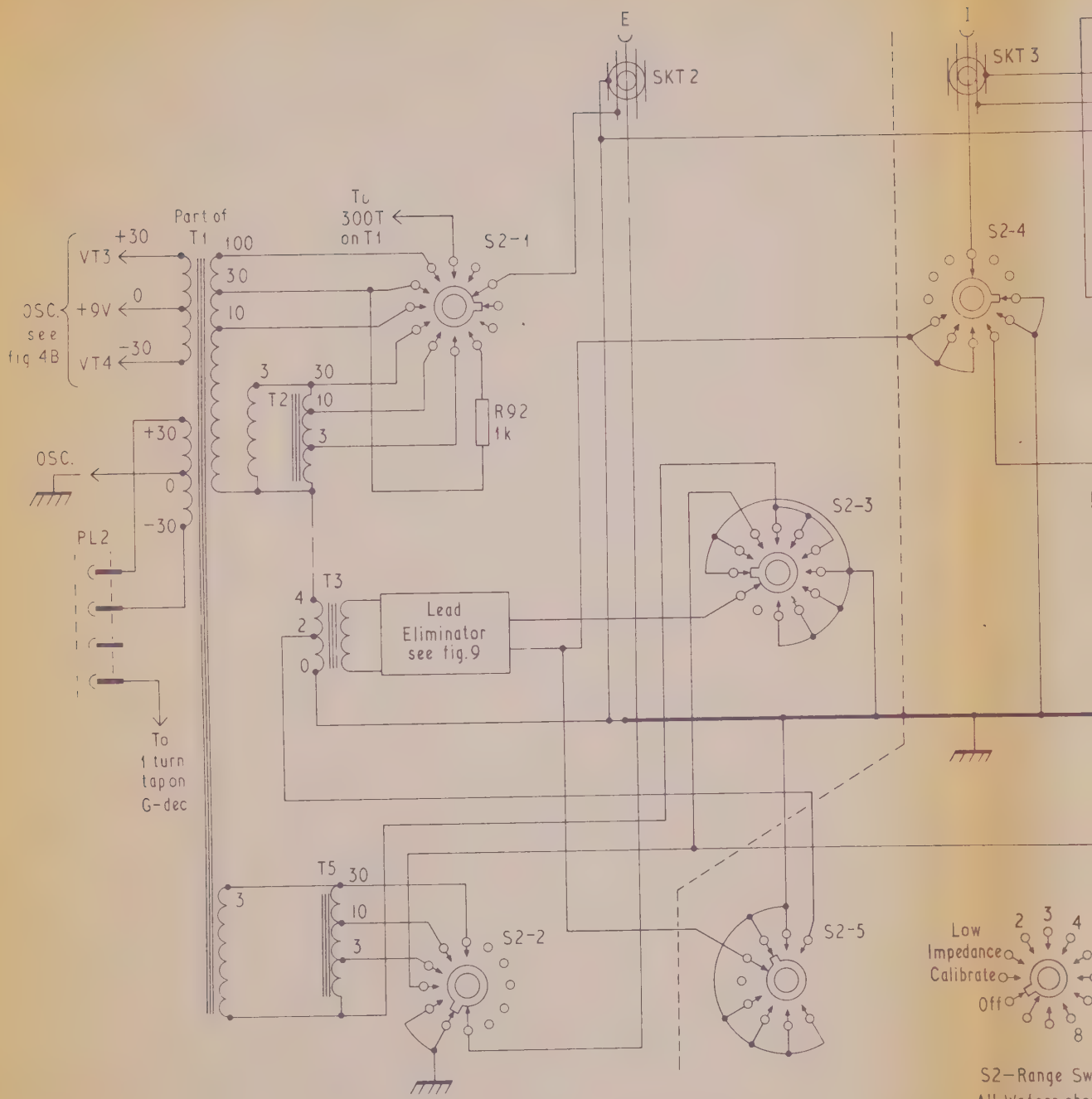
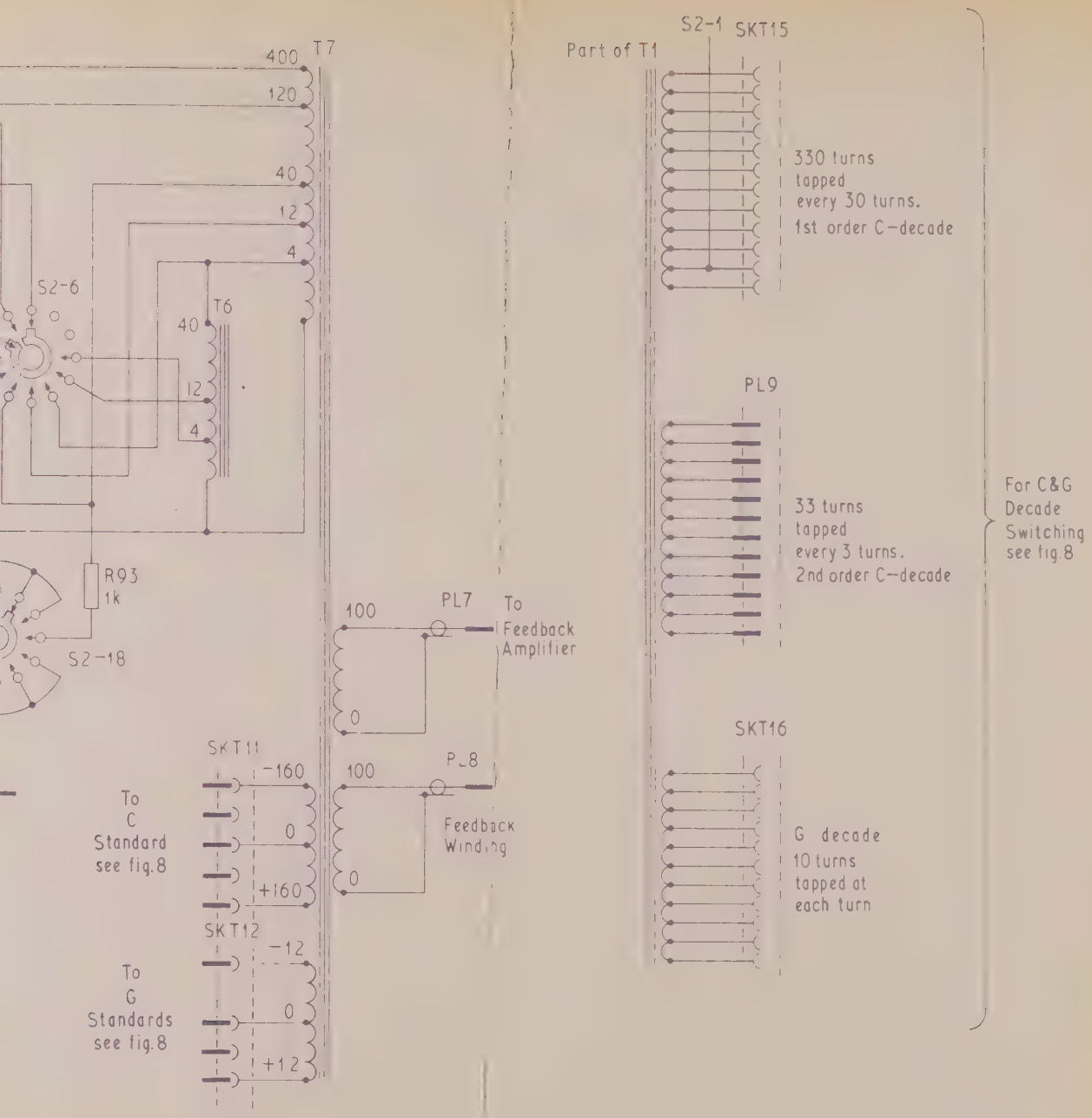
* in some models, frequency adjustment is either by means of a trimmer capacitor C60 or both C60 and RV18.



S2—Range Sw
All Waters sho
Off positio



B331 Nucleus Circuit Fig.5

31. The voltage from T1 (or T2 on ranges 2, 3 and 4) is fed via the switch S2/1 and the inner screen of the triax socket SKT2 (E) to the component under test. Current is then fed via the inner screen of triax socket SKT3 (I) and switch S2/6 to the current transformer T7 (T6 on ranges 2, 3 and 4). The inner screen of the triax connectors is used for the signal circuit in preference to the centre core because it is a heavier conductor and will therefore cause a smaller volt drop owing to the load current than would the centre core. On the other hand, the lead eliminator circuit takes an insignificant current and can therefore use the centre core of the triax connectors with impunity.

32. Lead Eliminator. The reference voltage E_{ref} referred to in para. 10 is taken from a three-turn winding on T1 and applied to the auto transformer T5. Transformers T5 and T2 are identical and so, if there were no losses, equal potentials would be applied at point (a) in Fig. 6 and the points (b) and (c) would be equi-potential. However, the current I_u causes a volt drop in the connections between T2 and Y_u so that the potential at (b) becomes lower than that at (c). This difference is fed to the lead eliminator amplifier (see para. 41) whose output is applied to transformer T3; the secondary winding of T3 is connected in series with the lower end of T2. Thus the lead eliminator output raises the potential level of T2 until the points (b) and (c) are in fact at equal potentials (equal, that is to say, within the limits of the system - see para. 11).

33. Bridge Nucleus in Low Impedance Measurements. It has been explained in para. 12 and 13 why the configuration of the Bridge is changed when measuring low impedances and this was illustrated in simple form in Fig. 3. The diagram in Fig. 7 shows in detail how the change is accomplished. Consider for a moment the simple circuit of Fig. 3. Though it was stated in para. 13 that the source side of the Bridge can be considered as a constant current generator, it will be appreciated that this is strictly so only if the impedance of Y_u is zero; similarly, the loading on the detector is negligible only when Y_u is small compared with the detector input impedance. Since the value of R92 is 1kΩ and the impedance of Y_u can vary between 0 and 10Ω, the maximum error would be 1%; also, since the input impedance of the detector is 1kΩ (R93), a further 1% error occurs when the impedance of Y_u is 10Ω.

34. On the Low Impedance range, the function of the Lead Eliminator is switched

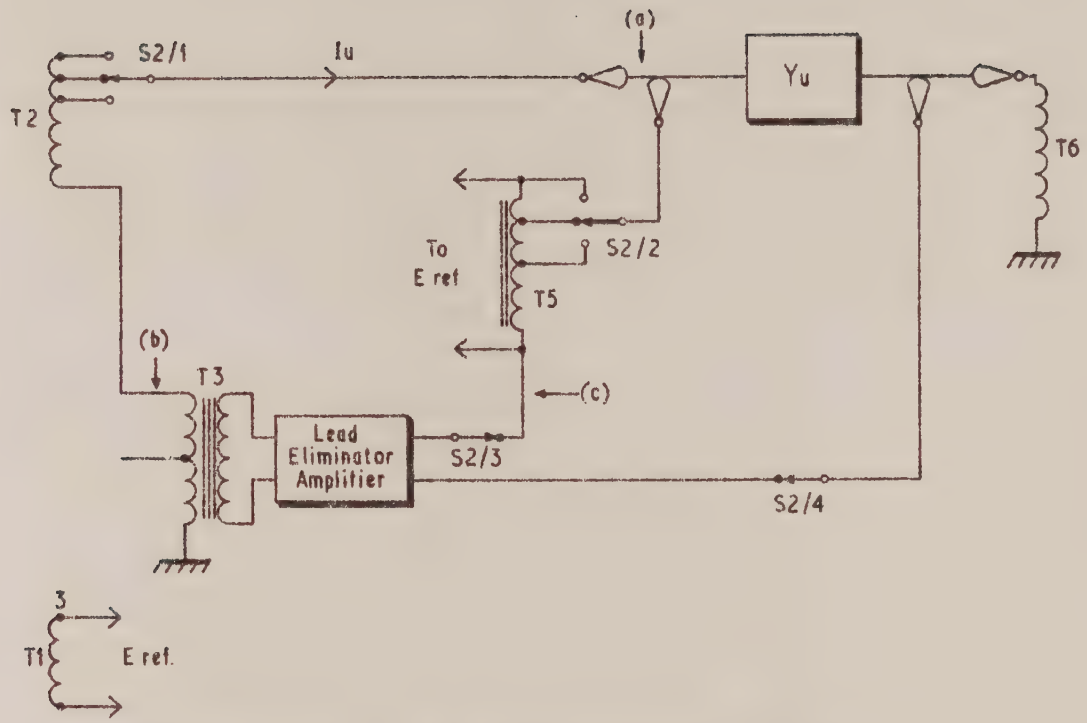


Fig.6 Connections to Lead Eliminator on Ranges 2,3 & 4

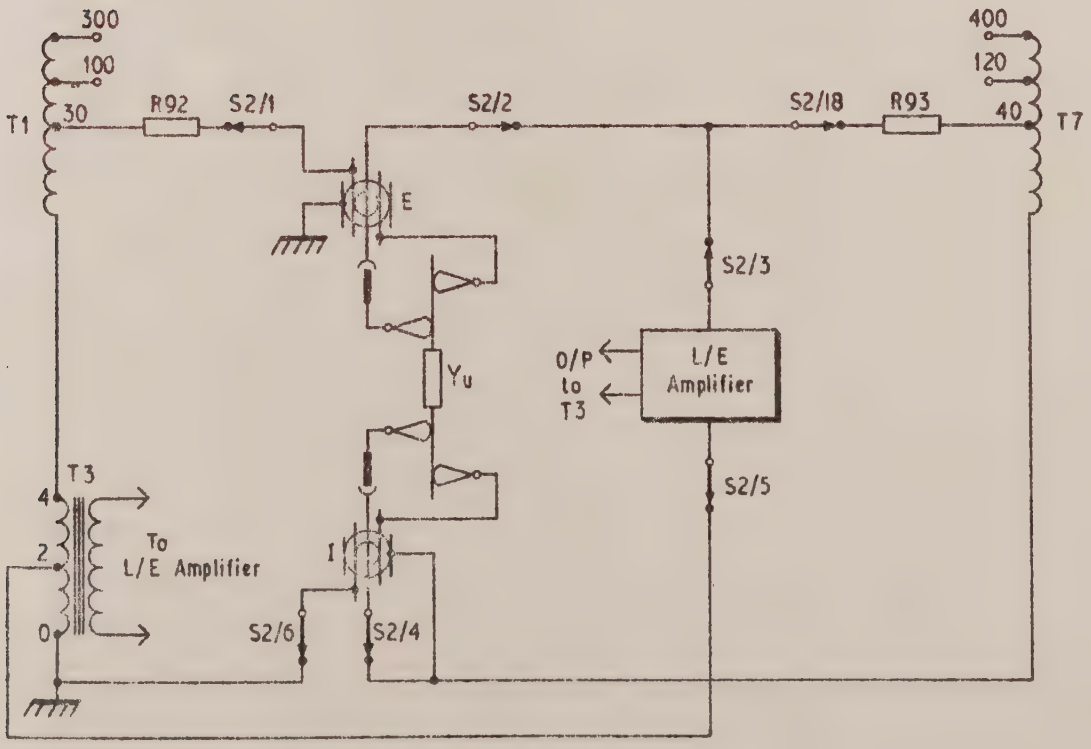
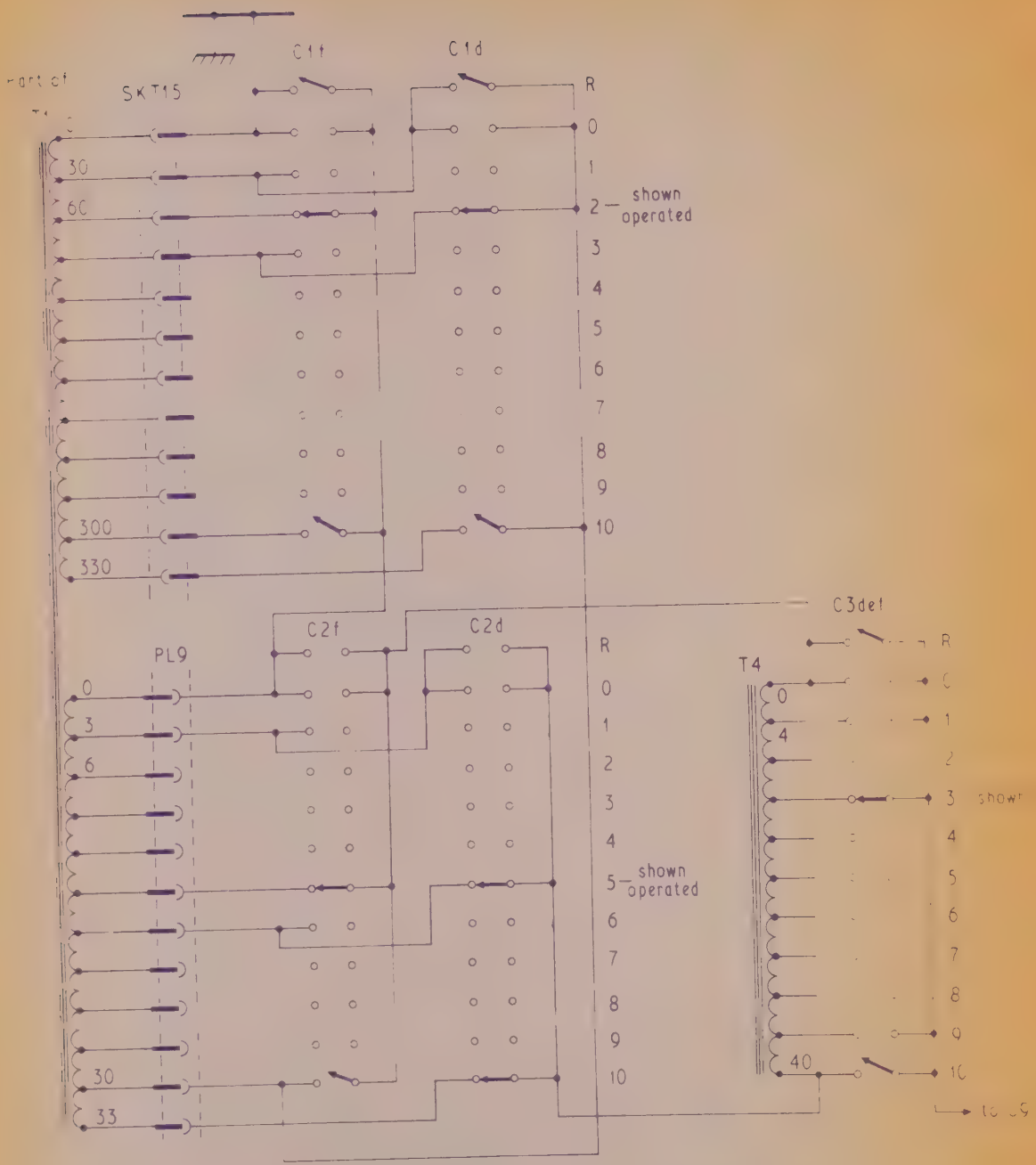


Fig.7 Connections to Unknown and Lead Eliminator on Range 1


C1f
C1d
SKT15
R
0
1
30
2
60
shown operated
3
4
5
6
7
8
9
300
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330
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C2d
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30
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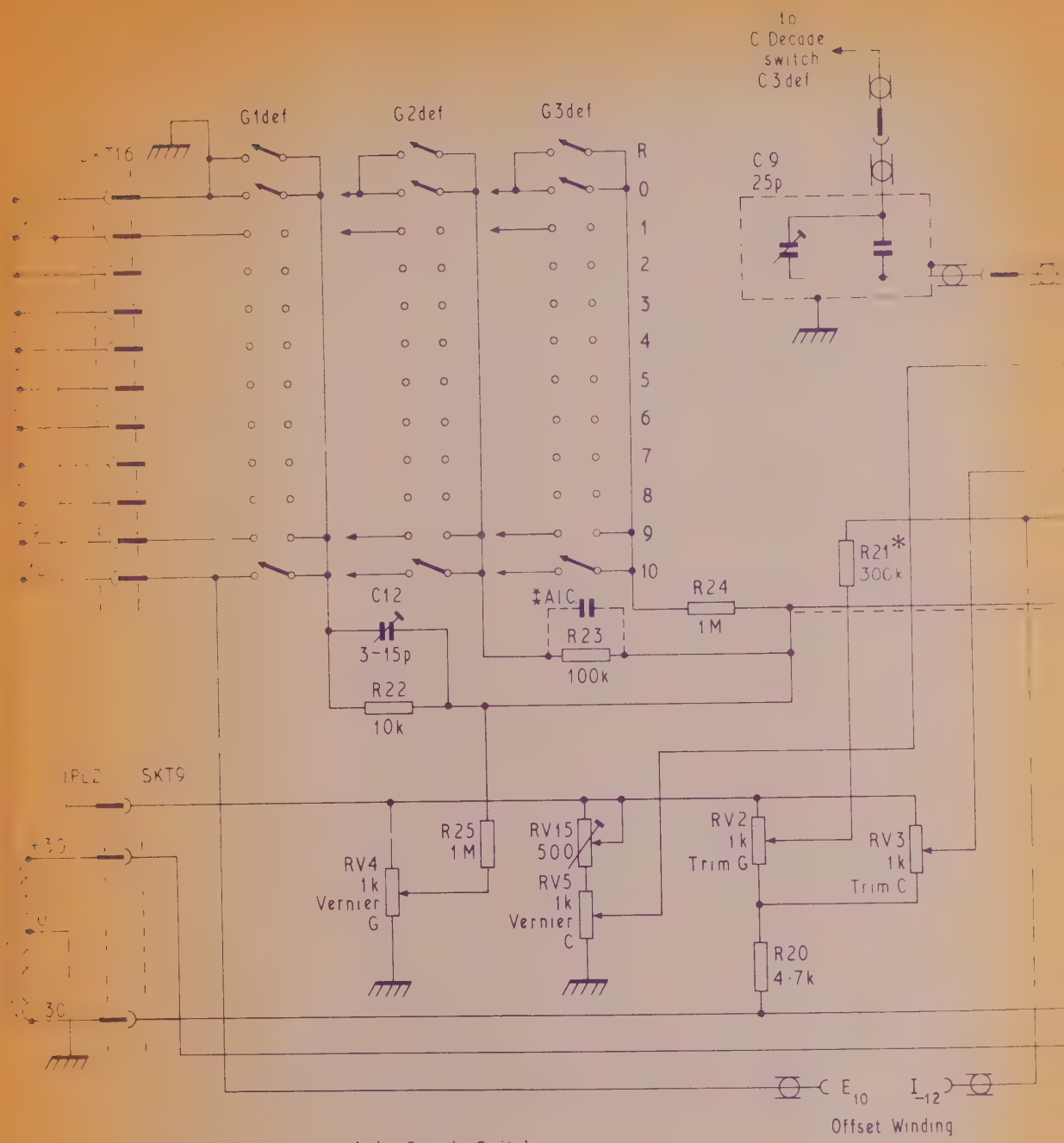
40

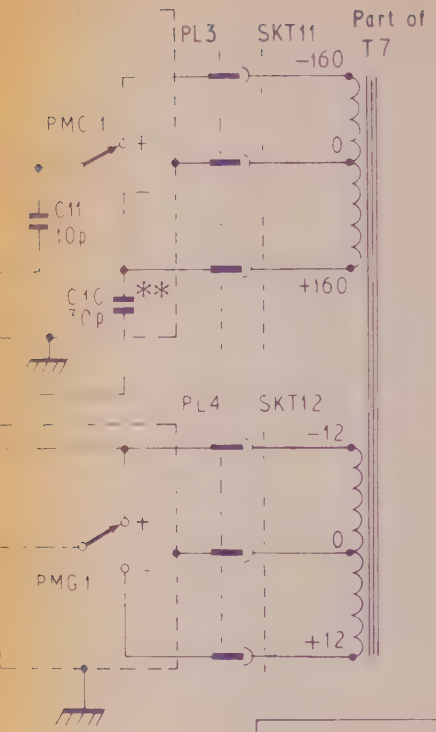


Note: For clarity, some of the Decade Switch connections are omitted but all contacts are similarly connected

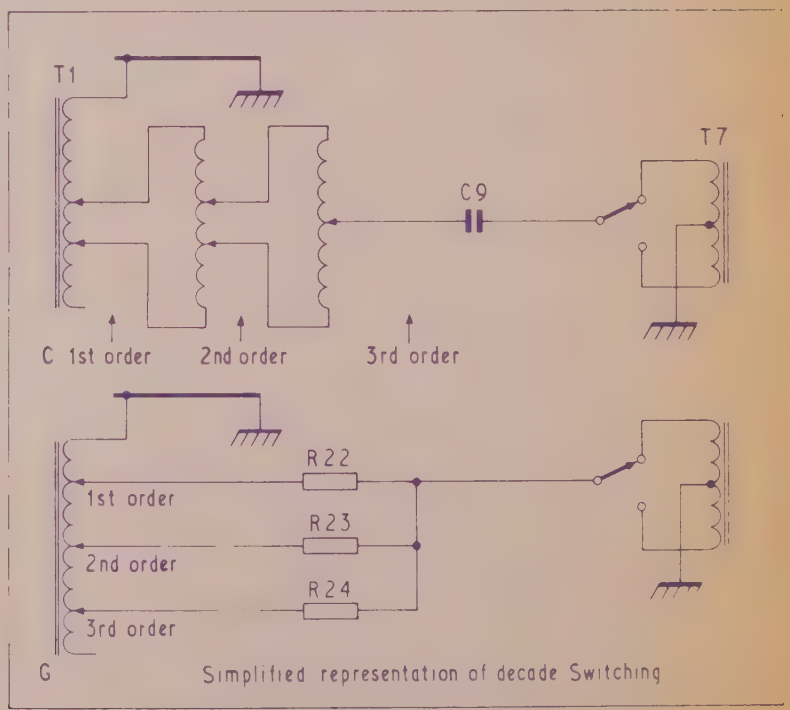
* 1MΩ on some instruments

** 10pF on some instruments

‡ A.I.C. capacitor fitted on some instruments



S2/10
S2/9
Fig. 15 Base Drive Amplifier



C & G Decade Switching and Standards Circuit Fig. 8

(see Fig. 7) so as to detect the voltage across the unknown and then to increase the source voltage (as on other ranges) but, instead of adjusting the voltage across the unknown to be equal to a reference voltage, it adjusts the source voltage to produce

(a) the correct nominal constant current in the unknown

(b) an additional current to offset the detector loading error.

Considering first (a) only, the lead eliminator amplifier would require a gain of unity because then, whatever the voltage across the unknown, on being applied to the lead eliminator the source voltage would be increased by an identical amount thus closely maintaining the constant current. In fact, the impedance of the voltage detector is the same as that of the current generator and so the gain required from the lead eliminator amplifier is two; this then produces the additional current (b). The amplifier gain of two is achieved by applying voltage feedback to the input-low terminal (the input being differential in nature) from a centre-tap on the L/E output transformer secondary.

Decade Switches and Bridge Standards

35. The decade switches are associated with the following circuits.

(a) The C and G decade windings on the voltage transformer T1.

(b) The decade indicator tubes.

(c) The operating sequence lamps.

The following paragraphs deal with item (a) above and explain the operation of the decades switches in conjunction with the C and G standards. The circuit diagram for this section of the instrument is given in Fig. 8.

36. C and G Standards. Before explaining the decade switching in detail, a few words about the standards themselves will explain the basic difference between the C and G systems. This difference is that whereas in the case of C there is one standard and three decade windings, in the case of G there are three standards and one decade winding. The reason for this is that resistors suitable in size, accuracy and stability for use as conductance standards are readily available, but this is not so with capacitors. In this application, long-term stability and low temperature coefficient are more important than absolute value. The capacitance standard used in the B331 has a stability that is measured in terms of only a few parts per million.

NOTE: THE STANDARD CAPACITOR C9 IS FILLED WITH DRY NITROGEN AND THEREFORE MUST NOT BE OPENED.

37. C Decades. The voltage transformer T1 has two C decade windings, the first of which consists of 330 turns tapped at every 30 turns; the second winding has 33 turns and is tapped at every third turn. The voltage from three turns of this second winding is fed to an auto transformer T4, which is divided by ten equi-spaced tappings. The first order decade switch connects the second order winding between any adjacent pair of taps on the first order winding. Similarly, the second order switch connects T4 between any adjacent pair of taps on the second order winding. Finally, the third order switch selects the appropriate tap on T4 and feeds the voltage at that point to the C standard, C9. This process is made clear in the simplified inset diagram in Fig. 8. Note that there are eleven taps on the first and second order decade windings; this allows a '10' to be included in the decade switches (the switches that control the indicator tubes are connected so as to provide a 'carry' facility). Thus the voltage applied to C9 can be set to four significant figures. Current from C9 is fed via the C polarity switch PMC1 to a +160 or -160 turn winding on T7.

38. G Decades. The G standards are fed from a single ten-turn winding on T1, tapped at each turn. A voltage selected from this winding by the first order G decade switch is fed to R22; a voltage selected from the same winding by the second order switch is fed to R23 (ten-times the value of R22); finally, and again from the same winding, the third order decade switch selects and feeds a voltage to R24 (one-hundred times the value of R22). The currents from these three standards are added together and fed via the G polarity switch PMG1 to a +12 or -12 turn winding on T7. This also is shown in a simplified form in the inset to Fig. 8. Trimmer capacitor C12, in parallel with R22, gives first order phase correction. Second order phase errors are corrected by means of a loop of tape foil round the second decade standard R23, the inductance of the tape cancelling the capacitance of the resistor. Third order phase errors are insignificant.

Bridge Trim and Vernier Controls

39. The one-turn tap on the G decade winding is fed to RV2 and RV3, the G and

C Trim controls respectively. The return path is via R20 to -30 turns on another winding of T1. The value of R20 is chosen to give approximately plus and minus one turn of voltage across the Trim potentiometers. The trim current is fed to the C and G windings of T7 via C10 and R21 respectively.

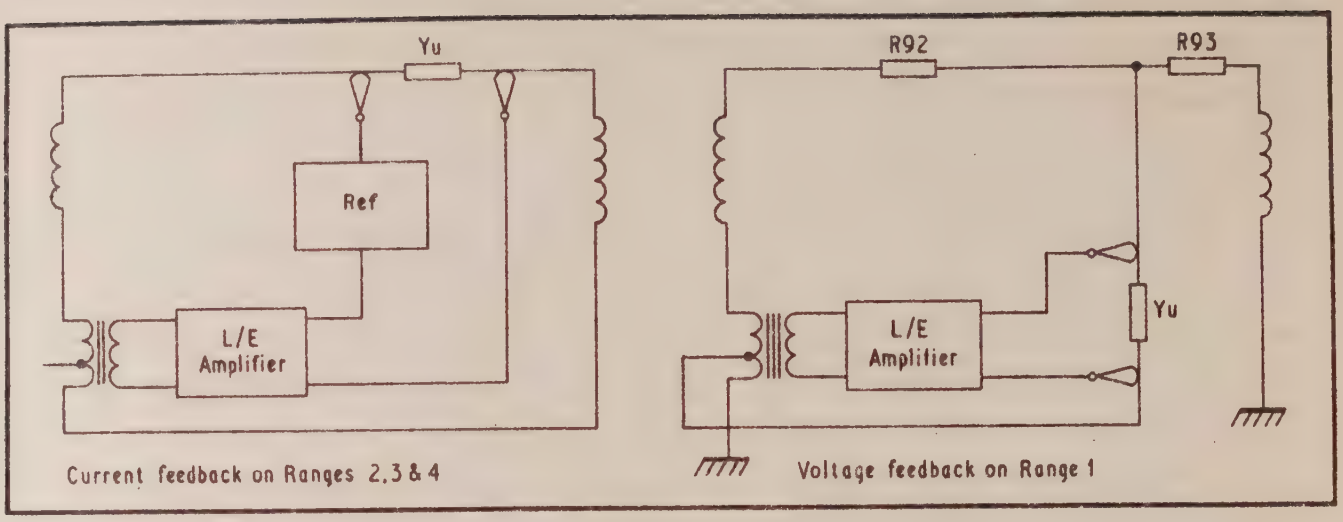
40. The one-turn voltage is also fed to RV4 (Vernier G) and RV5 (Vernier C). These controls are returned to ground and so each provides a variable offset voltage whose maximum is equivalent to full-scale deflection of the meters at maximum sensitivity. The C offset voltage is fed via C11, and the G offset voltage via R25 to T7. To compensate for tolerance in the value of C11, RV15 is added in series with RV5. Such adjustment is not necessary in the case of RV4 because R25 is a close-tolerance component.

Lead Eliminator Amplifier

41. The circuit diagram of the Lead Eliminator Amplifier is given in Fig. 9. The difference between the output from T5 and the potential across Y_u (see Fig. 6) is fed as a differential input between the base and emitter of VT22, whose collector load is the tuned circuit L4 and C48; this is tuned to the operating frequency of the bridge. Transistors VT23 and VT24 form a compound amplifying stage with feedback in the ratio of the impedance of the networks R87/R88/C51 and R89. D. C. feedback for the first two stages is obtained by connecting VT22 base bias R81/R85 to the emitter of VT23. The output of the amplifier is taken via C52 and the switches S2/19 and S2/8 to the primary of T3. Switches S2/19 and S2/8 reverse the phase of T3 primary on Range 1 (Low Impedance) as required by the fundamental difference in the application of the system for low impedance measurements (see inset on Fig. 9). The primary winding of T3 is short-circuited on Ranges 5 to 8 so as to avoid unwanted effects when the lead eliminator is not in use.

Feedback Amplifier

42. The Feedback Amplifier comprises a tuned preamplifier VT8/VT9 and a two-stage switched gain output amplifier VT29, VT10/VT11, VT12. The circuit diagram is given in Fig. 10. The output from the current transformer T7 is fed via C14 and R26 to the base of VT8, which with VT9 forms a d. c. feedback pair. The a. c. path for the emitter of VT9 is via R32 and C19; this, in conjunction



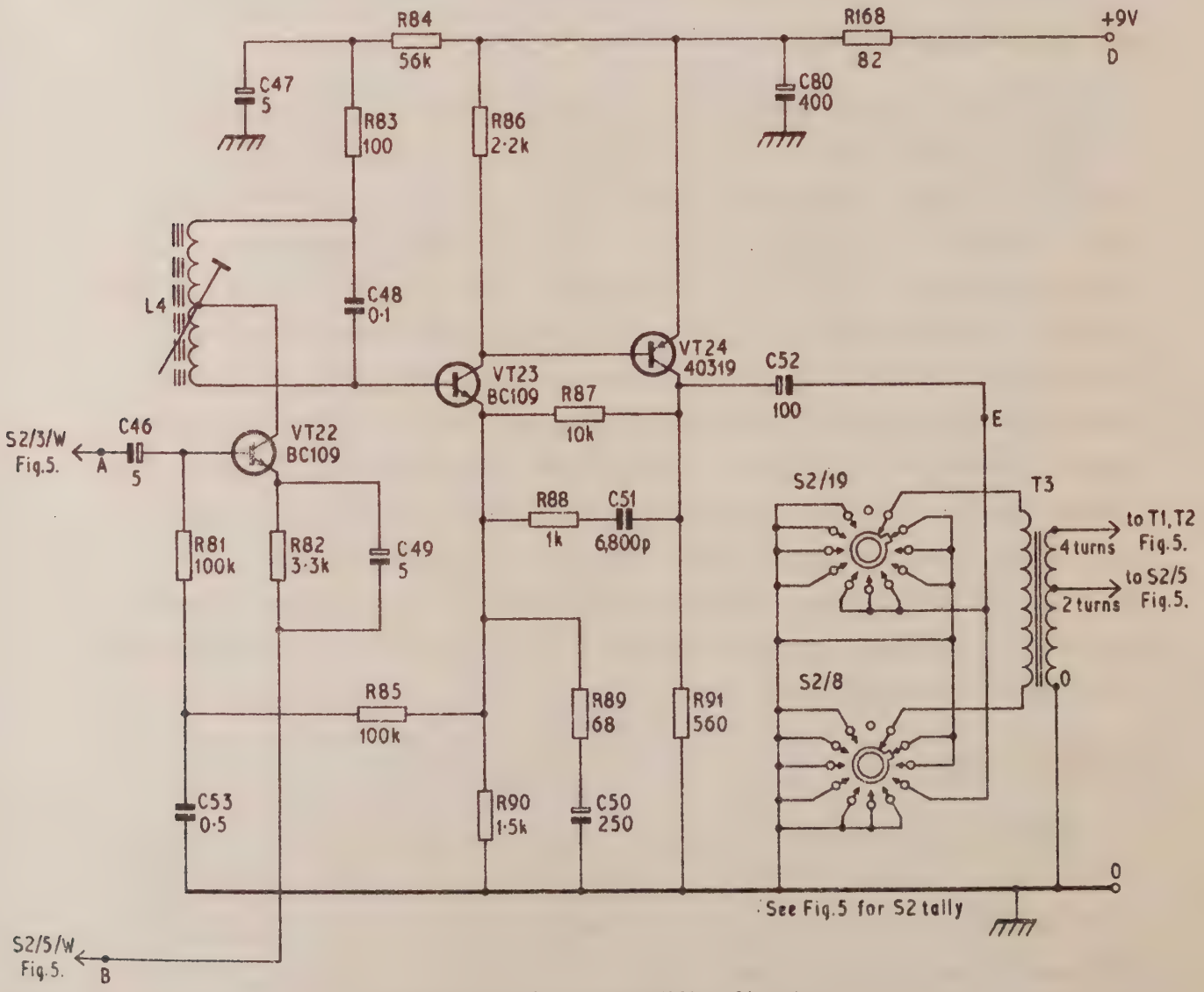
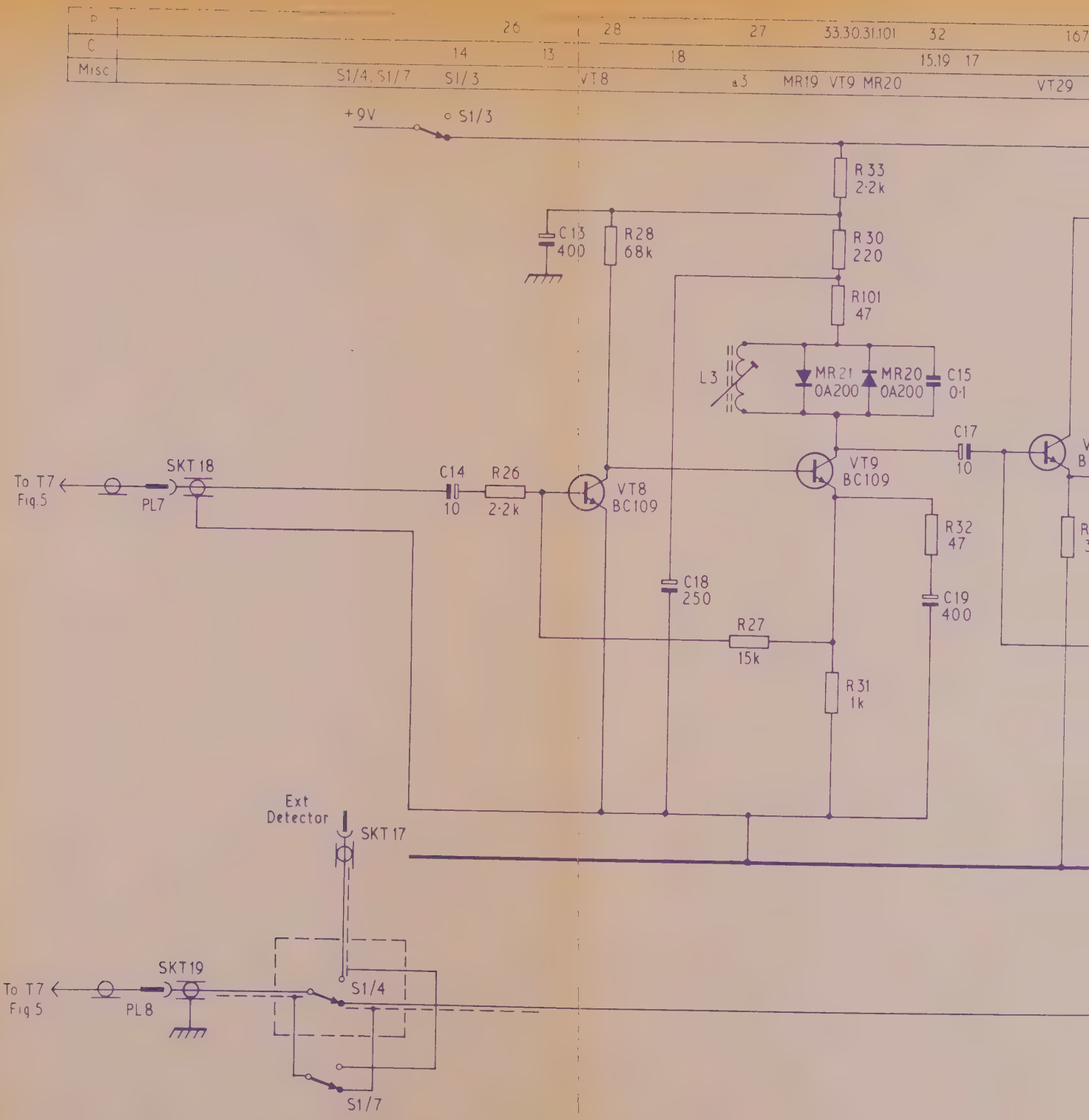
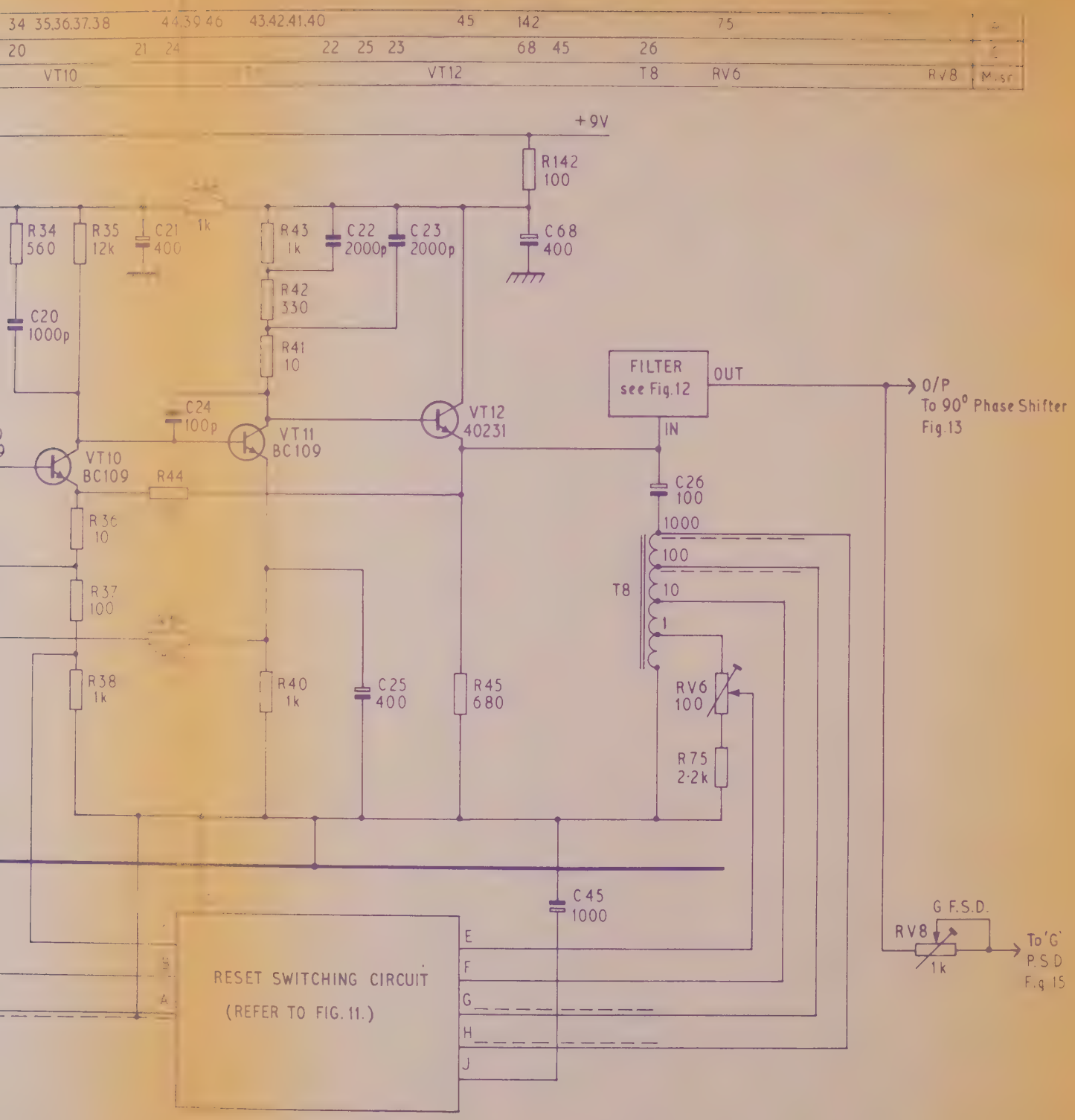


Fig.9 Lead Eliminator Amplifier Circuit


B
C
Misc
26
28
27
33.30.31.101
32
14
13
18
15.19
17
S1/4, S1/7
S1/3
VT8
L3
MR19
VT9
MR20
VT29
+9V
S1/3
R33
2·2k
C13
400
R28
68k
R30
220
R101
47
L3
MR21
0A200
MR20
0A200
C15
0·1
C17
10
SKT18
To T7
Fig.5
PL7
C14
10
R26
2·2k
VT8
BC109
VT9
BC109
R32
47
C18
250
C19
400
R27
15k
R31
1k
Ext
Detector
SKT17
SKT19
To T7
Fig 5
PL8
S1/4
S1/7



Feedback Amplifier Fig.10

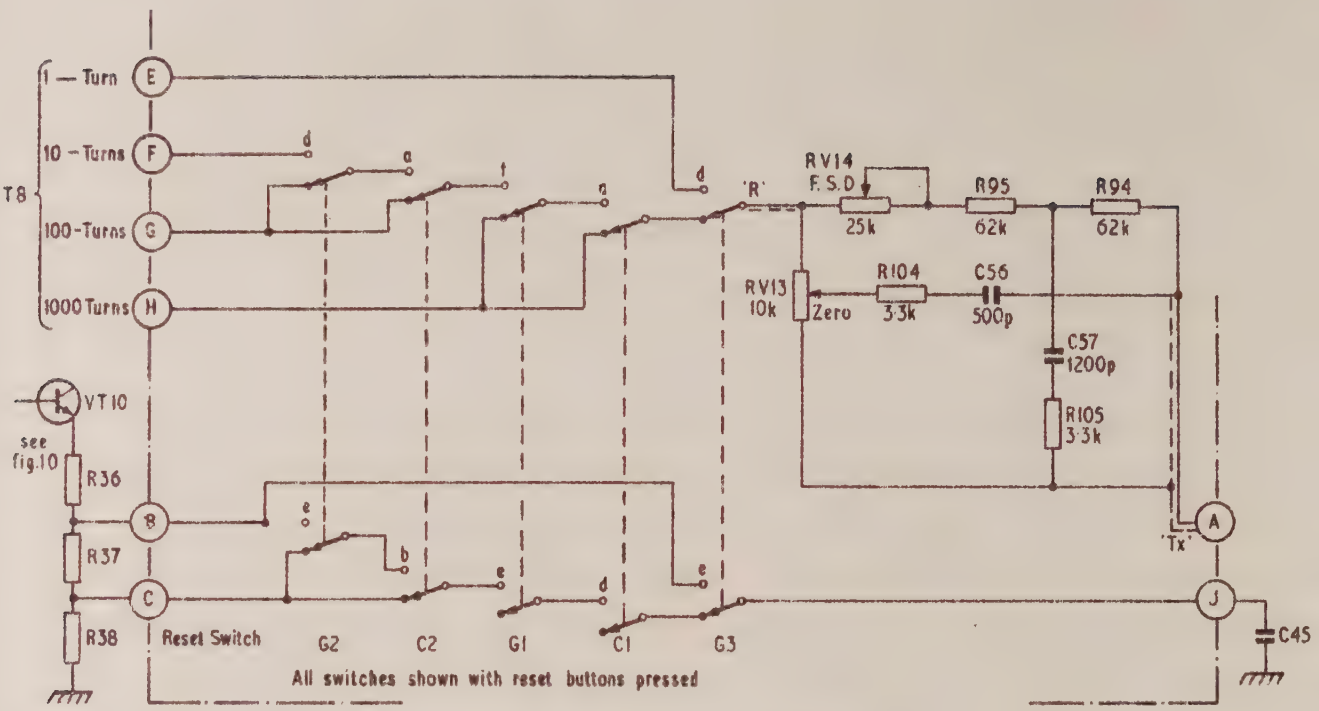
with the feedback resistor R27, gives the stage an alternating current gain of 50dB. The output current from VT9 drives the tuned circuit L3/C15 - tuned to the bridge frequency - so transforming the current into a voltage. The overall voltage gain of the stage is 86dB. The diodes MR20, MR21 in the tuned circuit have no effect under normal conditions of operation but, under overload conditions, they restrict the output from VT9 and prevent the system from becoming paralysed.

43. The output from VT9 is fed via C17 and the buffer stage VT29 to the base of the variable gain stage VT10. The network R34/C20 in parallel with the collector load of VT10 controls the high frequency response of the amplifier; the networks in the collector circuit of VT11 have a similar function, the overall effect being to prevent the fall in open-loop gain from exceeding 30dB per decade. The emitter load of VT10 is in three sections R36, R37 and R38; the decoupling capacitor C45 is switched by the Reset circuits (see Fig. 11) so as to be either open-circuit or to decouple R38 or R37 and R38 together.

44. Transistor VT11 is a straightforward driver stage feeding the emitter follower output stage VT12. There are two d. c. feedback paths, one from VT12 emitter back to VT10 emitter (this is also the a. c. feedback path) and the other from VT11 emitter back to VT29 base. This arrangement gives a very high degree of d. c. stability. The output from the emitter of VT12 is fed via C26 to the feedback transformer T8; this has a winding of 1000 turns and is tapped at 100 turns, 10 turns and 1 turn. Selection of the 100-turn tap and the connection of C45 to the junction of R37/R38 is synchronous with the operation of the first order decade. Operation of the second order decade connects C45 to the junction of R36/R37 and selects the 10-turn tap on T8. Finally, operation of the third order decade selects the 1-turn tap on T8, leaving the connection of C45 unchanged. This arrangement preserves the stability of the system by keeping the loop gain within reasonable limits.

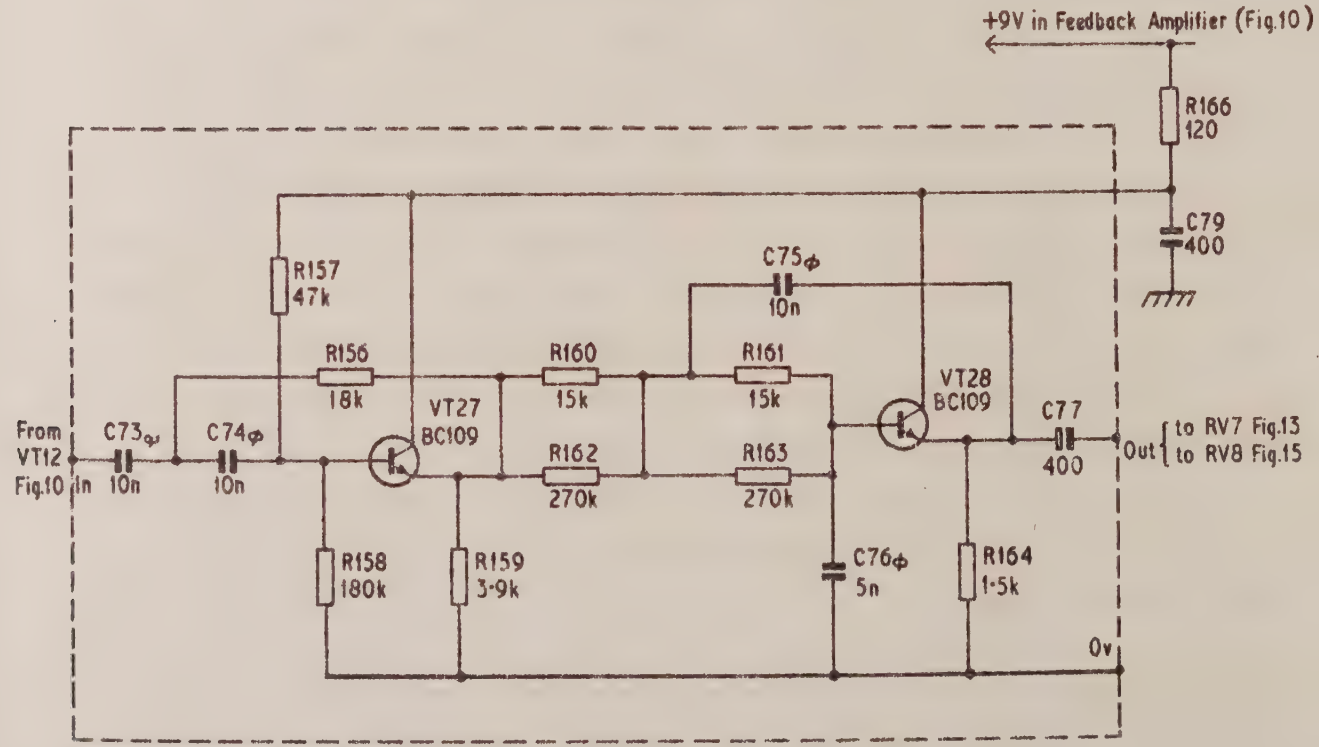
Reset Switching

45. The reset switching, shown in Fig. 11, performs two functions, namely, it switches the decoupling capacitor C45 to the appropriate point on VT10 emitter circuit and it switches the feedback network between the appropriate tap on feedback transformer T8 and the feedback winding on current transformer T7.



Note: Lettered terminations correspond with block in Feedback Amplifier circuit Fig.10.

Fig.11 Reset Switching Circuit



Comp Ref.	φ Frequency of Operation 1000Hz	1592Hz	
C73	10n	6·28n	
C74	10n	6·28n	
C75	10n	6·28n	
C76	5n	3·14n	

Fig.12. Band Pass Filter Circuit

The main feedback resistance (R_f in Fig. 2) is the sum of resistors R94, R95 and RV14; the remaining components in the network, RV13, R104, R105, C56 and C57, correct the feedback phase angle. The potentiometers RV13 and RV14 are adjusted during the calibration check prior to actual measurements. It will be seen from Fig. 11 that the third order G decade has overriding control over all other decades; thus when the third order G button 1 is pressed during the Calibrate procedure (see Operating Instructions) the feedback amplifier assumes its most sensitive condition and the 'standard' current selected should produce f. s. d. on the G meter. Potentiometer RV14 adjusts the feedback resistance to achieve this condition. Under these conditions, with no 'unknown' current and no capacitive 'standard' current, the output from the C p-s detector will be zero if the feedback amplifier phase is correct; RV13 is adjusted until it is (i. e. until the C meter indication is zero).

Bandpass Filter

46. Before passing to the phase-sensitive detectors, the feedback amplifier output is fed to the bandpass filter circuit comprising VT27, VT28 and their associated circuits; these are given in Fig. 12. The filter response is centred on the bridge operation frequency. In the measurement of inductance it is particularly important that the signal should be free from harmonics; this is because the unknown and standard arms of the bridge react differently, especially to the odd harmonics, and would thus introduce serious errors. The chosen oscillator circuit gives a good sinusoidal output but the filter is included to remove residual harmonic frequencies. It will be seen from Fig. 12 that the circuit associated with VT27 constitutes a high-pass section whilst that of VT28 constitutes a low-pass section.

90° Phase Shifter

47. Since the capacitance component of the output from the feedback amplifier is in quadrature with the detector reference signal, the output must be fed through a 90° phase shift circuit before it can operate the C meter circuit. The circuit of the 90° phase shifter is given in Fig. 13.

48. The output from the bandpass filter is fed via the preset phase correcting network RV7 and C27 to an operational amplifier comprising VT13, VT14 and VT21.

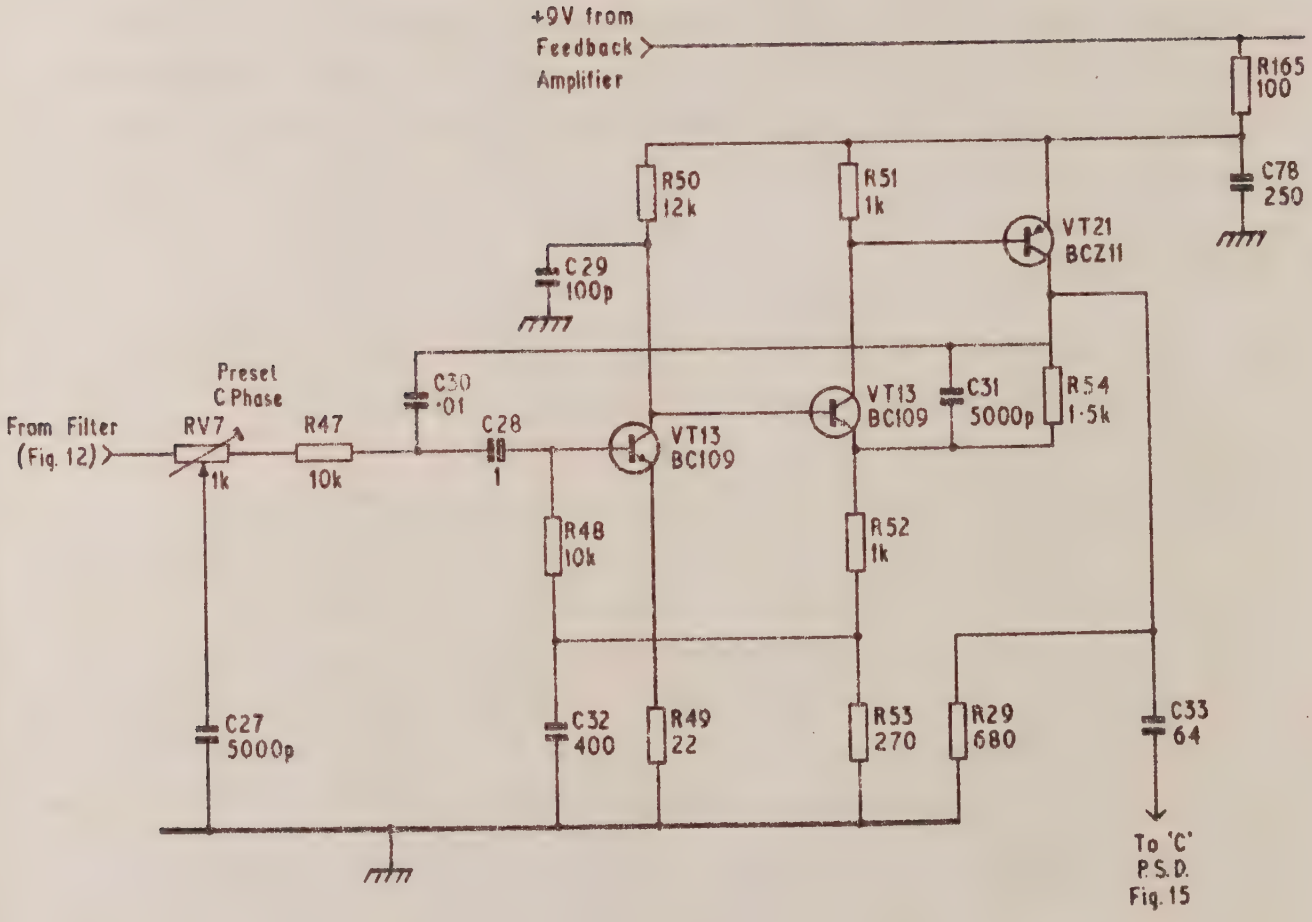


Fig. 13. 90^0 Phase Shifter

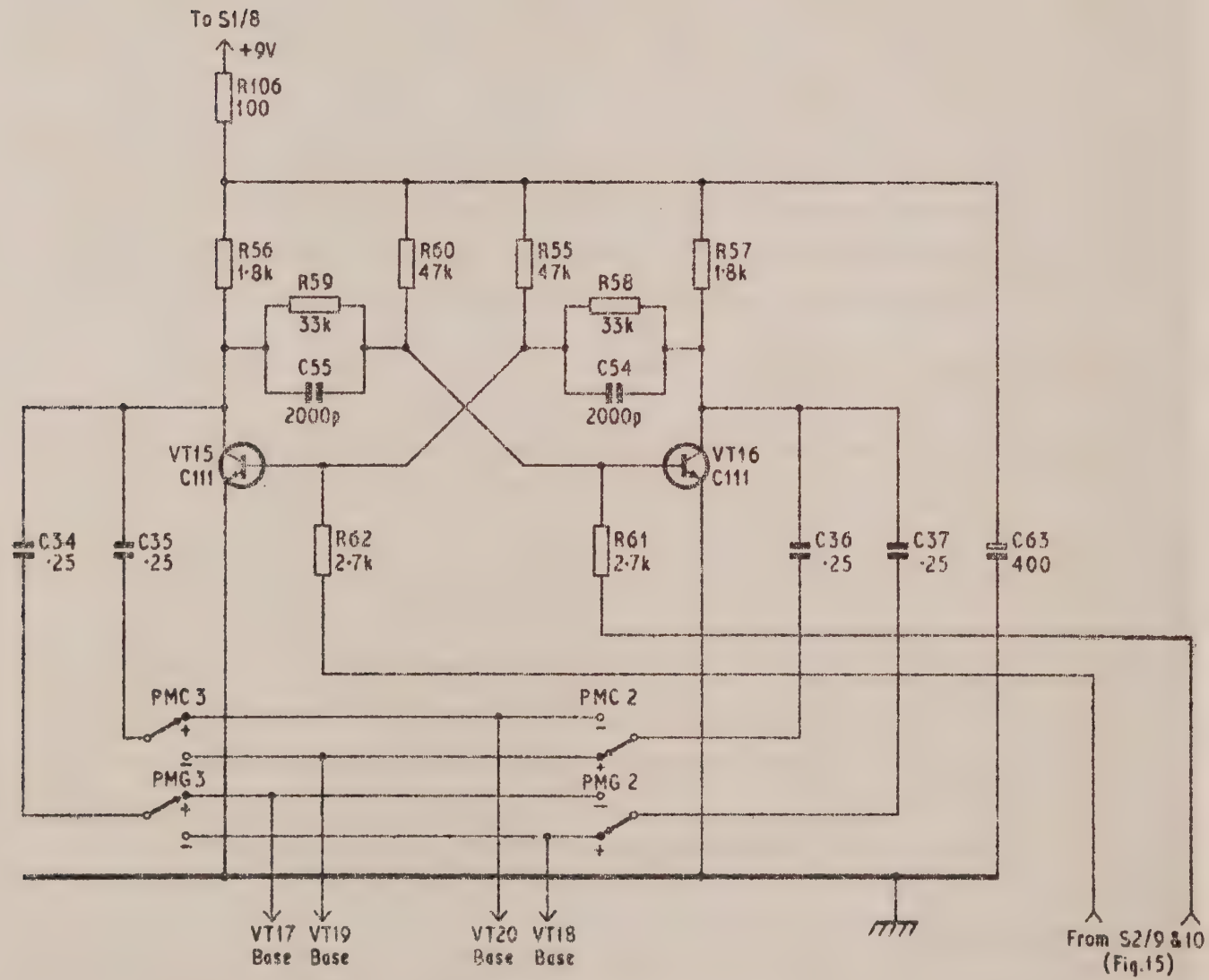


Fig.14 Base Drive Amplifier

Potentiometer RV7 allows the phase shift to be set exactly to 90°. The gain of the system is determined chiefly by the input resistor R47 and the feedback capacitor C30. The capacitors C29 and C31 improve the stability of the circuit.

Base Drive Amplifier

49. The purpose of the Base Drive Amplifier, whose circuit is given in Fig. 14, is to provide a fast switching waveform for the base circuits of the two phase-sensitive detectors. Transistors VT16 and VT17 form a regenerative switching circuit that is used here to shape the sinusoidal signal from the ±30-turn winding on T1 (see Fig. 8).

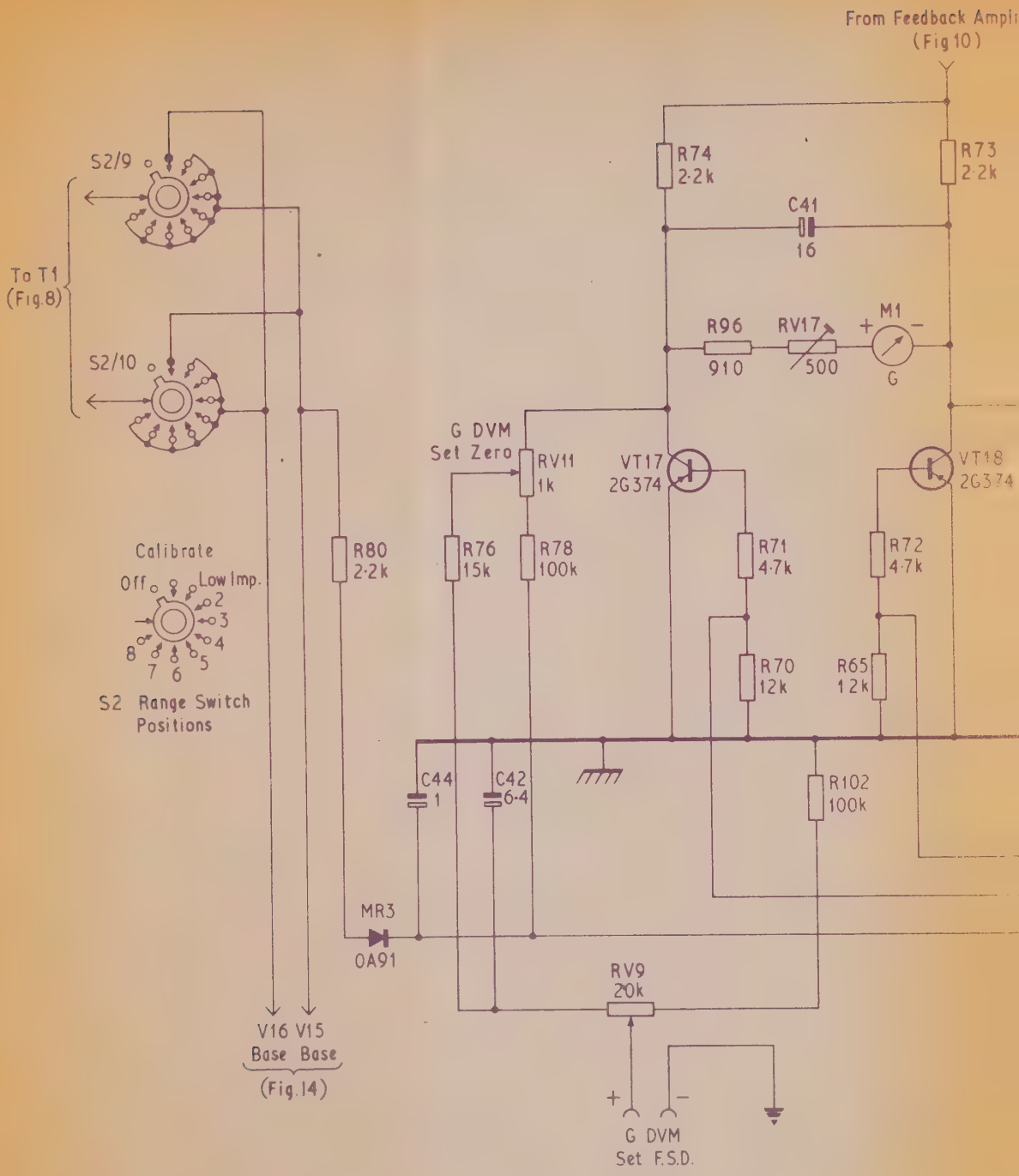
50. Two outputs are taken from each side of the Base Drive Amplifier, C35/C36 feeding the C detector, and C34/C37 feeding the G detector. In both cases the output is fed via the appropriate polarity switch so that the phase of the reference signal from the oscillator can be reversed when required.

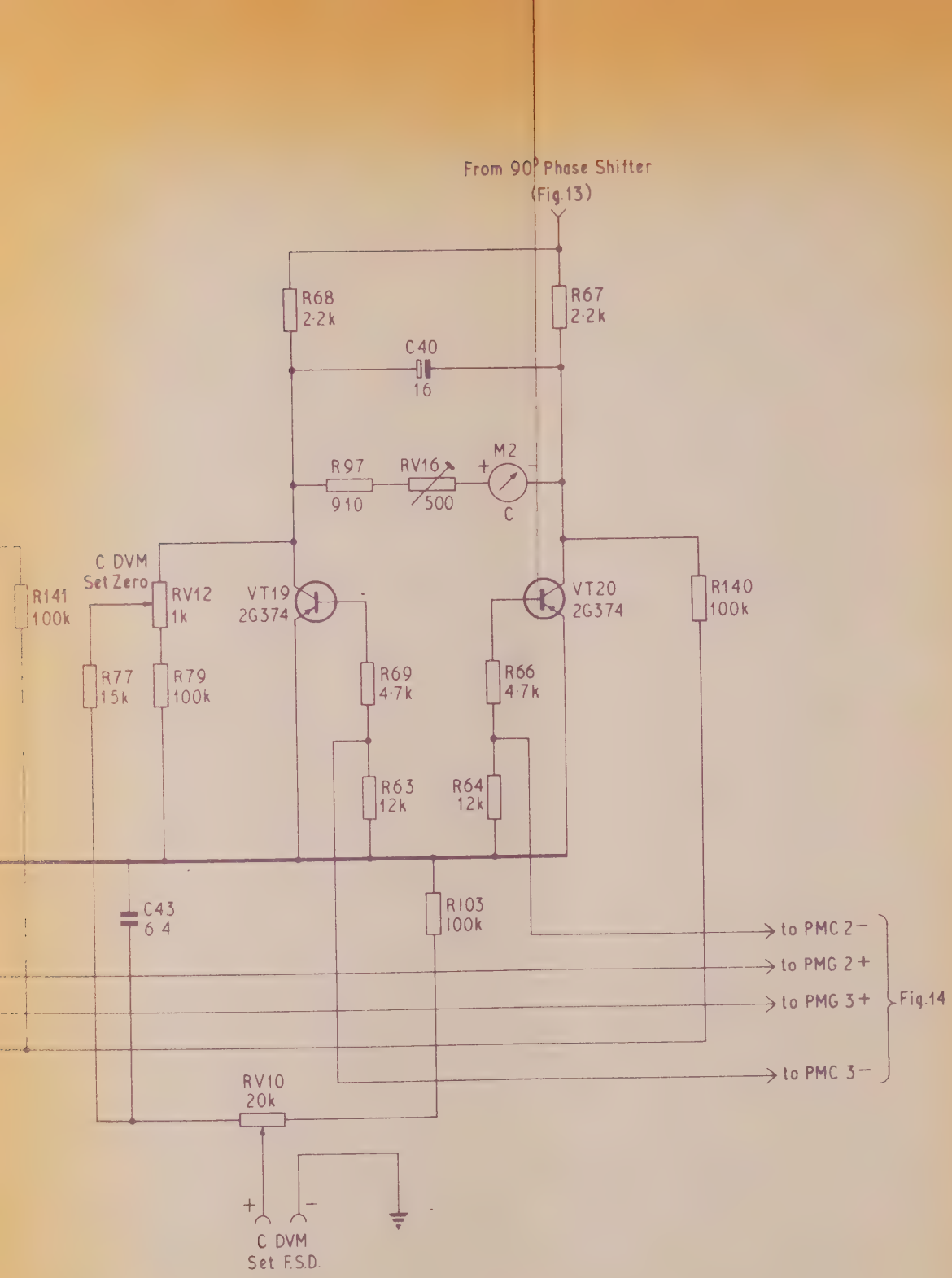
Phase-Sensitive Detectors

51. The two meters are each operated by identical phase-sensitive detectors, VT17/VT18 for conductance and VT19/VT20 for capacitance. The circuit diagram is given in Fig. 15. Consider the G p-s detector. Square waves from the base drive amplifier are applied in phase opposition to VT17 and VT18 bases so that these transistors conduct on opposite alternate half-cycles of the base waveform. When the input signal via RV8 is positive-going, the negative terminal of the meter is connected to ground and vice versa; thus the detector behaves in a manner similar to that of a full-wave rectifier but is phase sensitive. The base waveform is derived from the oscillator via the voltage transformer and the base drive amplifier and so it is in synchronism with the detector input.

DVM Outputs

52. The C and G phase-sensitive detectors each incorporate a circuit whose purpose is to provide a voltage output with respect to ground (chassis) that is proportional to the meter indication and which can be used to operate a digital voltmeter or recorder. For ease of understanding, the DVM output components associated with the G detector are shown separately in the scrap circuit Fig. 16.


From Feedback Ampli
(Fig 10)
R74
2·2k
R73
2·2k
C41
16
S2/9
To T1
(Fig.8)
S2/10
R96
910
RV17
500
M1
G
G DVM
Set Zero
RV11
1k
VT17
2G374
VT18
2G374
R76
15k
R78
100k
R71
4·7k
R72
4·7k
R80
2·2k
Calibrate
Off
Low Imp.
2
3
4
5
6
7
8
S2 Range Switch
Positions
R70
12k
R65
12k
C44
1
C42
6·4
R102
100k
MR3
OA91
RV9
20k
V16 V15
Base Base
(Fig.14)
+
−
G DVM
Set F.S.D.



Phase Sensitive Detectors Fig. 15

From this diagram, the corresponding components for the C detector can be readily identified but note that R80, MR3 and C44 are common to both detectors.

53. The circuit is necessary because although the meter indication is a steady direct voltage, both sides are approximately balanced about ground potential and so the meter voltage is not directly suitable as a DVM output. When the p-s detector transistors are conducting, the associated meter is not connected to ground potential exactly, but to a few millivolts negative with respect to ground (by virtue of the emitter/collector potential). To counteract this, a voltage is taken from T1, rectified and smoothed by R80, MR3 and C44, and fed via R78 and RV11 to one side of the meter. The correcting voltage is also fed via R141 to the other side of the meter so as to preserve the symmetry of the p-s detector. A voltage is taken from the slider of RV11 and fed via the 1592Hz ripple filter R76/C42 to the potentiometer RV9. Potentiometer RV11 is adjusted to give zero G-DVM output when the G meter indicates zero; RV9 adjusts the G-DVM output to accommodate various values of load impedance.

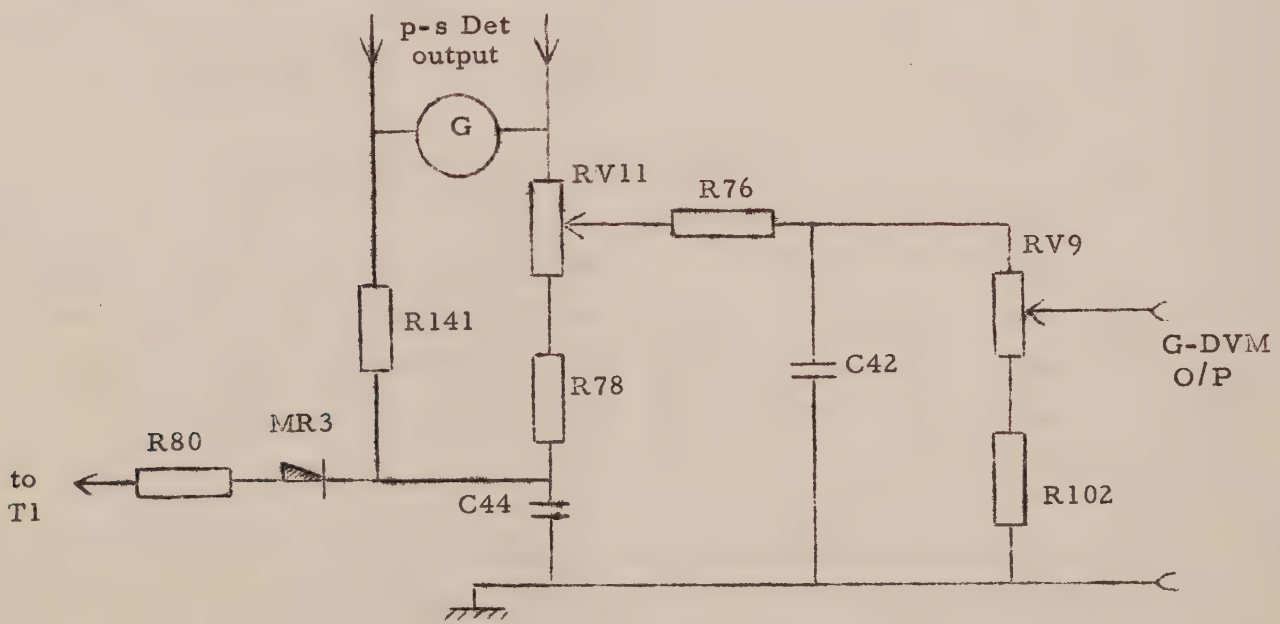


Fig. 16. DVM Output Circuit

Indicator Switching

54. **Decade Indicators** The illuminated display of the values of capacitance and conductance is given by means of digital display tubes, four tubes and three decimal point indicators for each. The display tubes are energized by means

of the push-button decade switches, each decade comprising eleven numeral buttons (0 - 10 inclusive) and a reset button. The anode of each display tube is connected via a load resistor to a 200V supply and the operation of any decade button between 0 and 9 connects the appropriate cathode to ground (see Fig. 17). The circuit is so arranged that when button 10 on a lower order decade is operated, the next higher order display tube indicates a numeral which is greater by one than the operated button for that tube; at the same time, the lower order display tube shows 0 (e. g. if the first order button 4 and second order button 10 are operated, the display tubes indicate 5.0). This system operates through all three decades so that if, for example, the display indicates 5.99 and the third order button 10 is then pressed, the display will indicate 6.00.

55. For ease of understanding, the simplified decade switching diagram given in Fig. 17 shows a simple two-decade system. Reference to Fig. 18 shows the complete system extended to cover three decades. However, this extension necessitates the addition of the diodes MR8 to MR11 whose purpose is to block alternative paths to ground that would otherwise exist. Thus

MR8 prevents V2 cathode '1' from lighting when the '10' button of decade 1 is operated

MR9 prevents V3 cathode '0' from lighting when the '10' buttons of both decade 1 and decade 2 are operated

MR11 prevents V3 cathode '0' from lighting via switch C2b'9'

MR10: operation of the '10' button on the third decade transfers the ground connection to the 'carry' line of the second decade, but an alternative path to ground would exist for the second decade via MR11 and C2b'9'; this is blocked by MR10.

56. Operating Sequence Indicators. These indicators are the illuminated arrowheads to the right of each decade that show the correct order for the operation of the decades. Figure 19 shows how the indicators are interconnected with the decade reset buttons. This diagram shows the starting condition, with all reset buttons pressed, in which the first C decade indicator is illuminated. This indicator has the G3b'0' and G3b'1' contacts in its circuit so that the indicator is switched off when the third G decade buttons 0 and 1 are operated (out of the normal sequence) during the Calibrate procedure (see Operating Instructions). By remembering that as each decade is operated the reset button for that

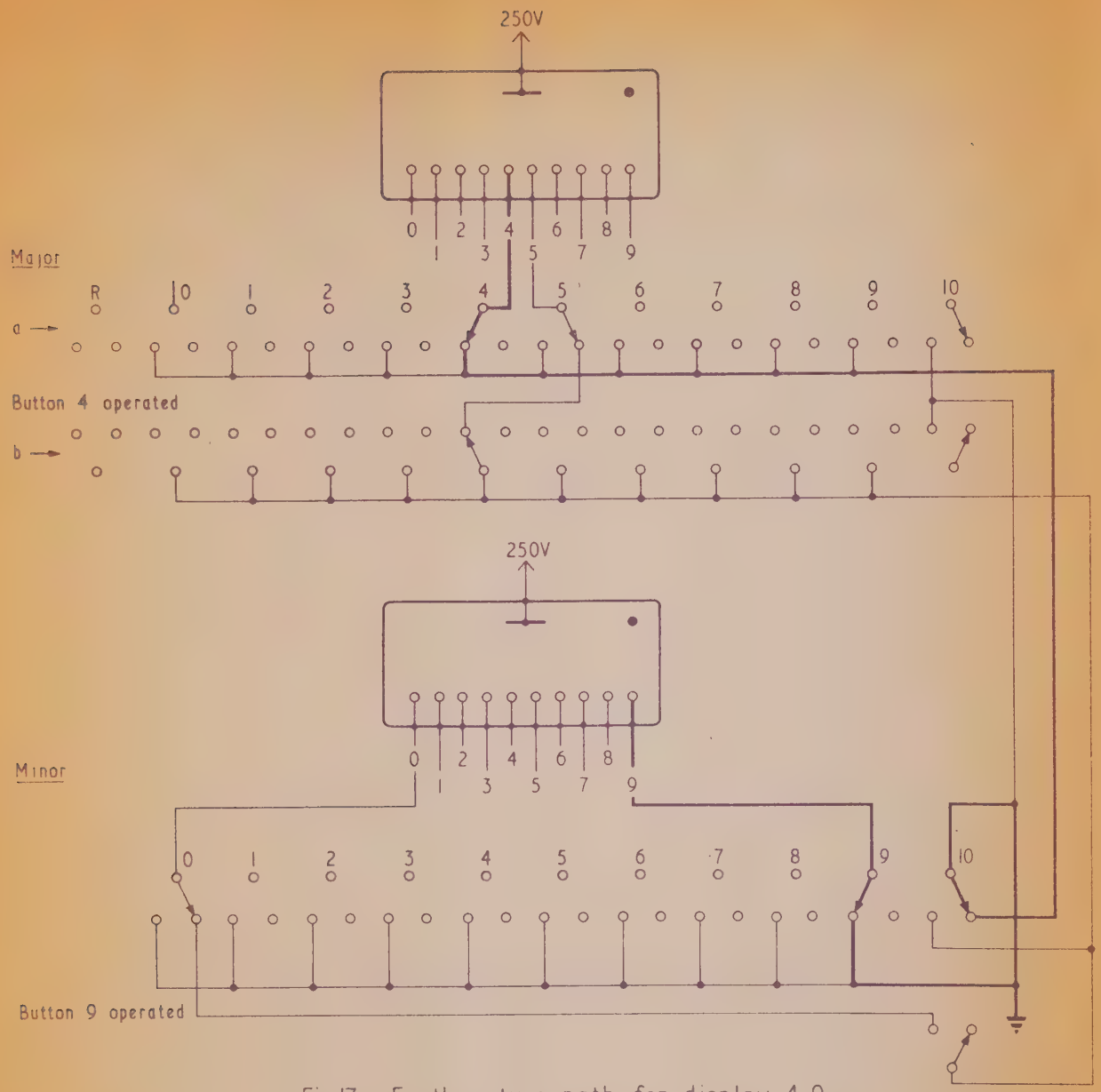


Fig.17a Earth return path for display 4·9

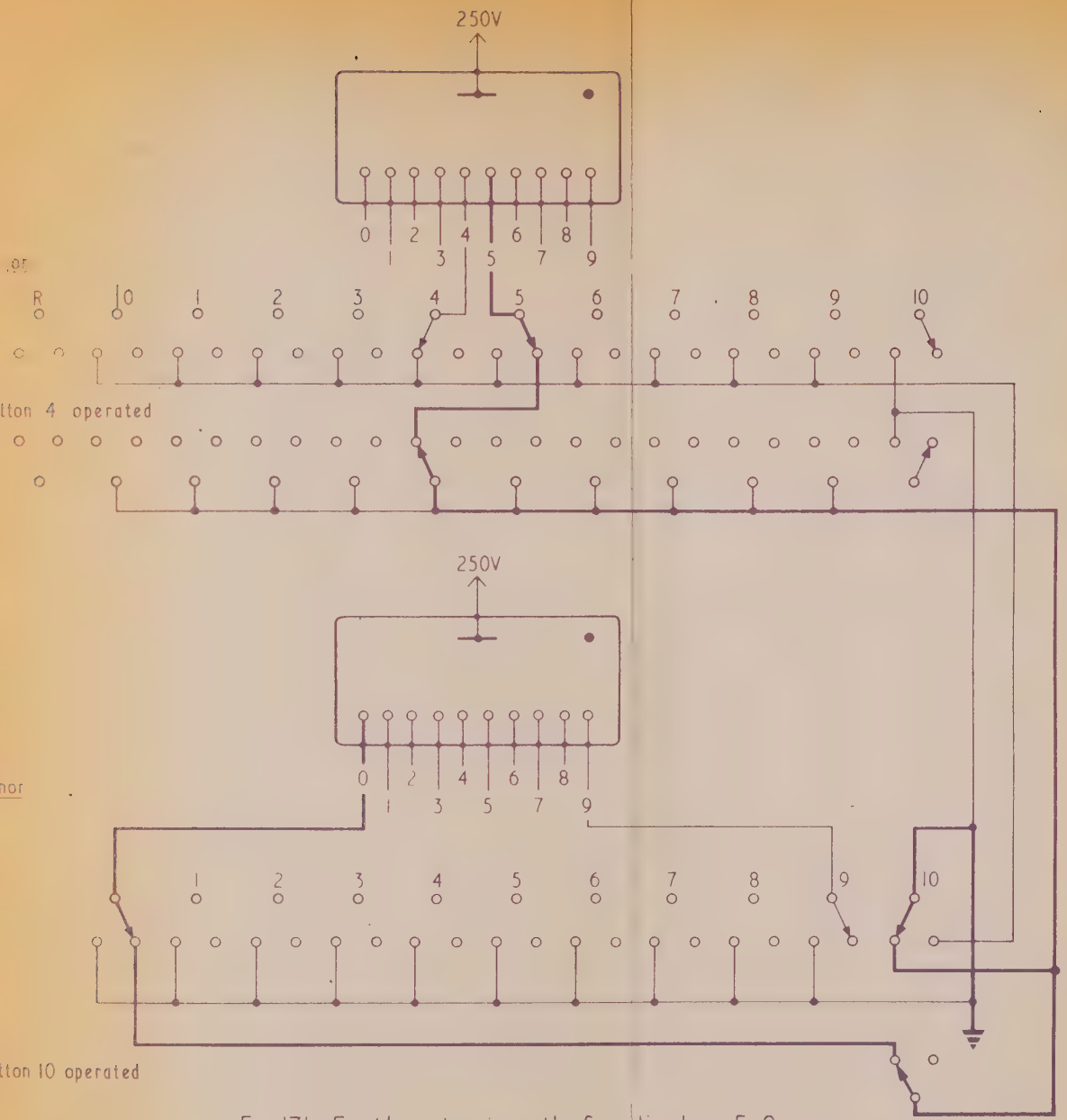
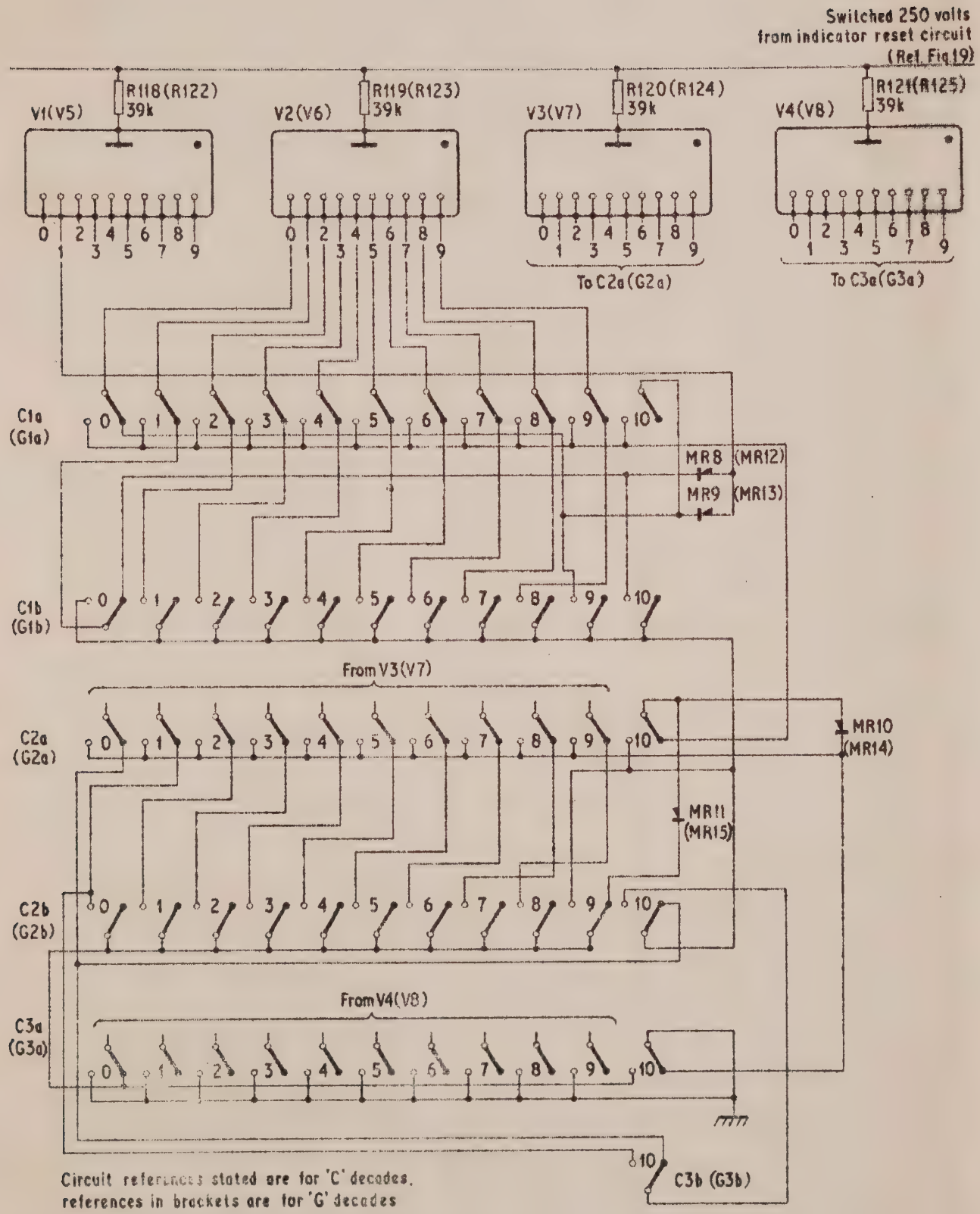


Fig.17b Earth return path for display 5·0 when buttons 4·10 are operated

Simplified Diagram of Digital Indicator Switching Fig.17



Digital Indicator Switching Fig. 18

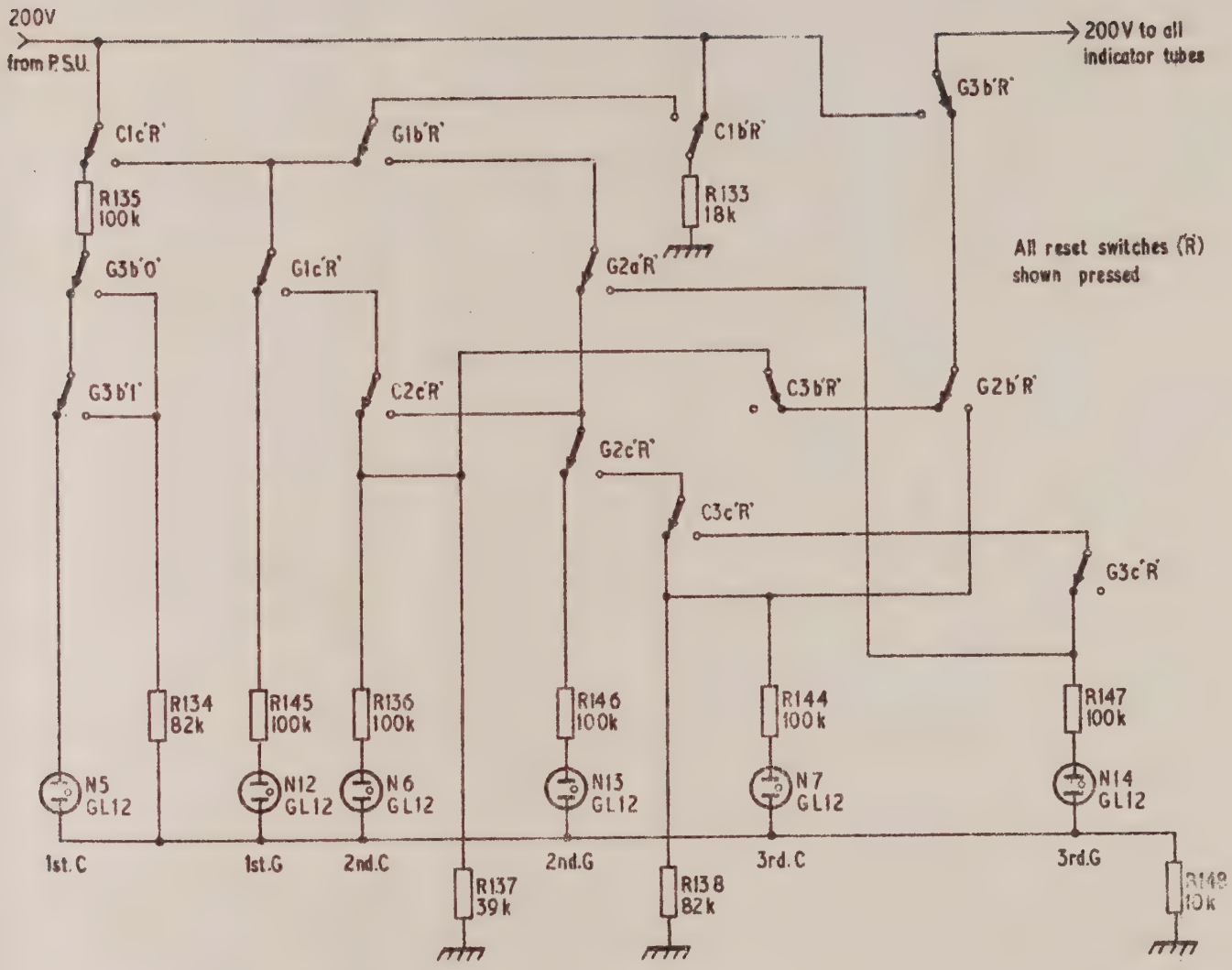


Fig. 19 Sequence Indicator Switching

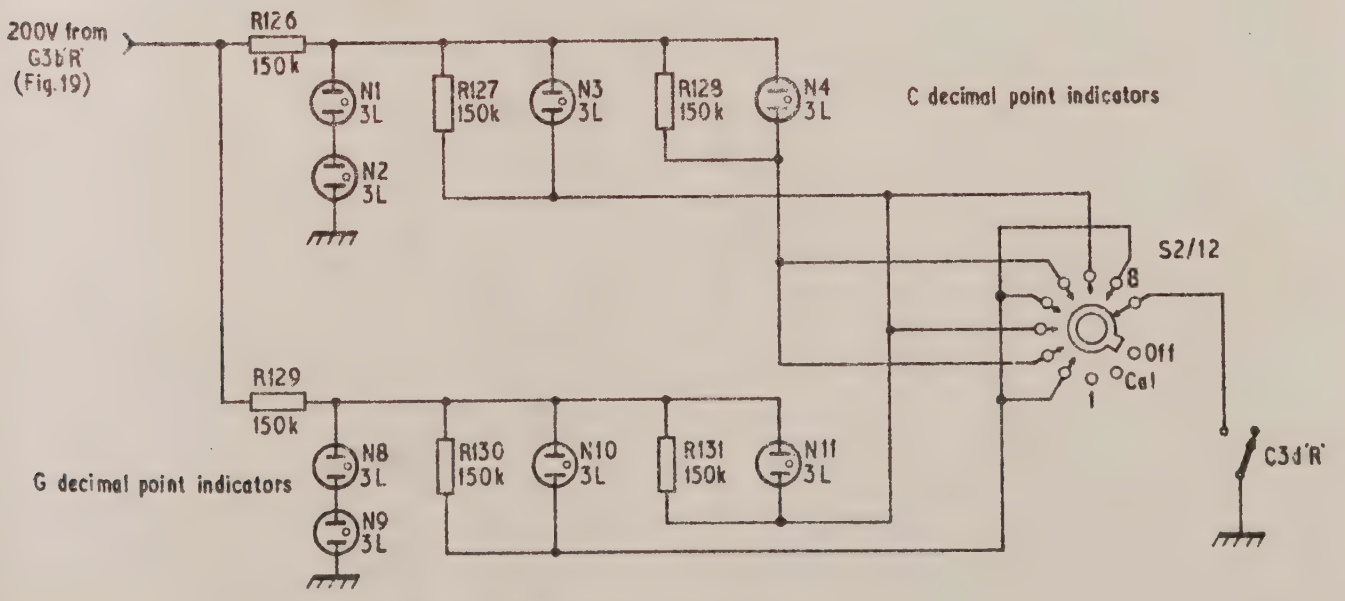


Fig. 20 Decimal Point Indicators

decade changes over, the energizing path for each indicator can be traced. This diagram also shows how the digital tubes are energized only when the appropriate G decade is operated.

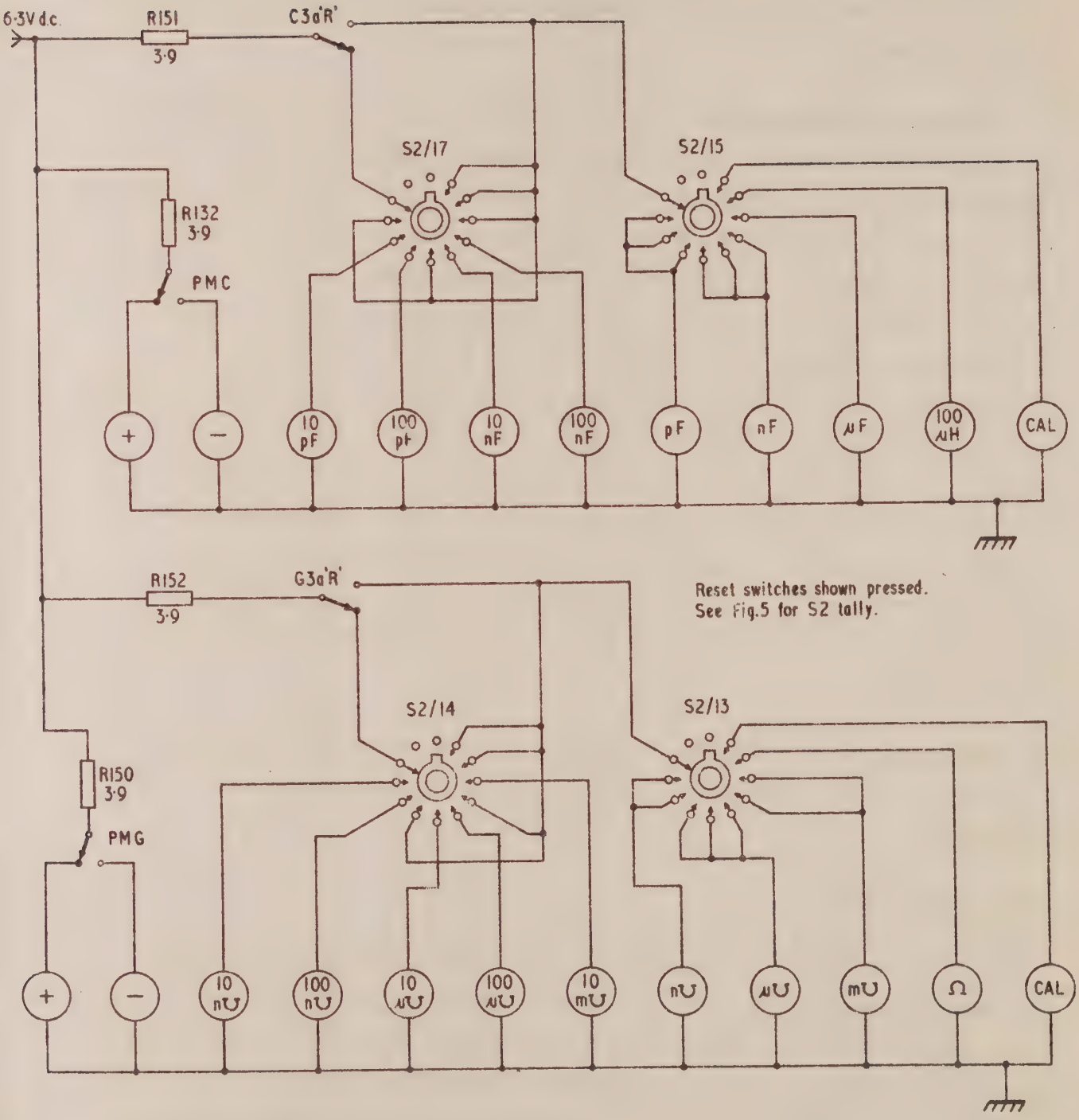
57. Decimal Point Indicators. The circuit diagram for the decimal point indicators is given in Fig. 20. Both the C and G indicators operate in a similar manner. The indicators are shown in Fig. 20 in the same relative positions as they appear on the instrument when viewed from the front. Initially, the reset switch C3d'R' removes the ground return for all except the left-hand indicators; these each comprise two tubes in series but only one in each pair is visible at the front panel. With the ground return removed from the centre and right-hand tubes, the left-hand pair of tubes (C or G) operate. As soon as a ground connection is made for the centre or right-hand tubes, the tube strikes and reduces the voltage across the tubes to approximately 50V. This is sufficient to strike one tube but not two tubes in series and so the left-hand tubes are extinguished. This arrangement reduces the complexity of the indicator switching. The purpose of the parallel resistors is to reduce the current through the single tubes to approximately the same as that taken by the two tubes in series, thus equalizing the brightness.

58. Range Multiplier Switches. The circuit diagram for these is given in Fig. 21. The switching is straightforward and requires no further explanation.

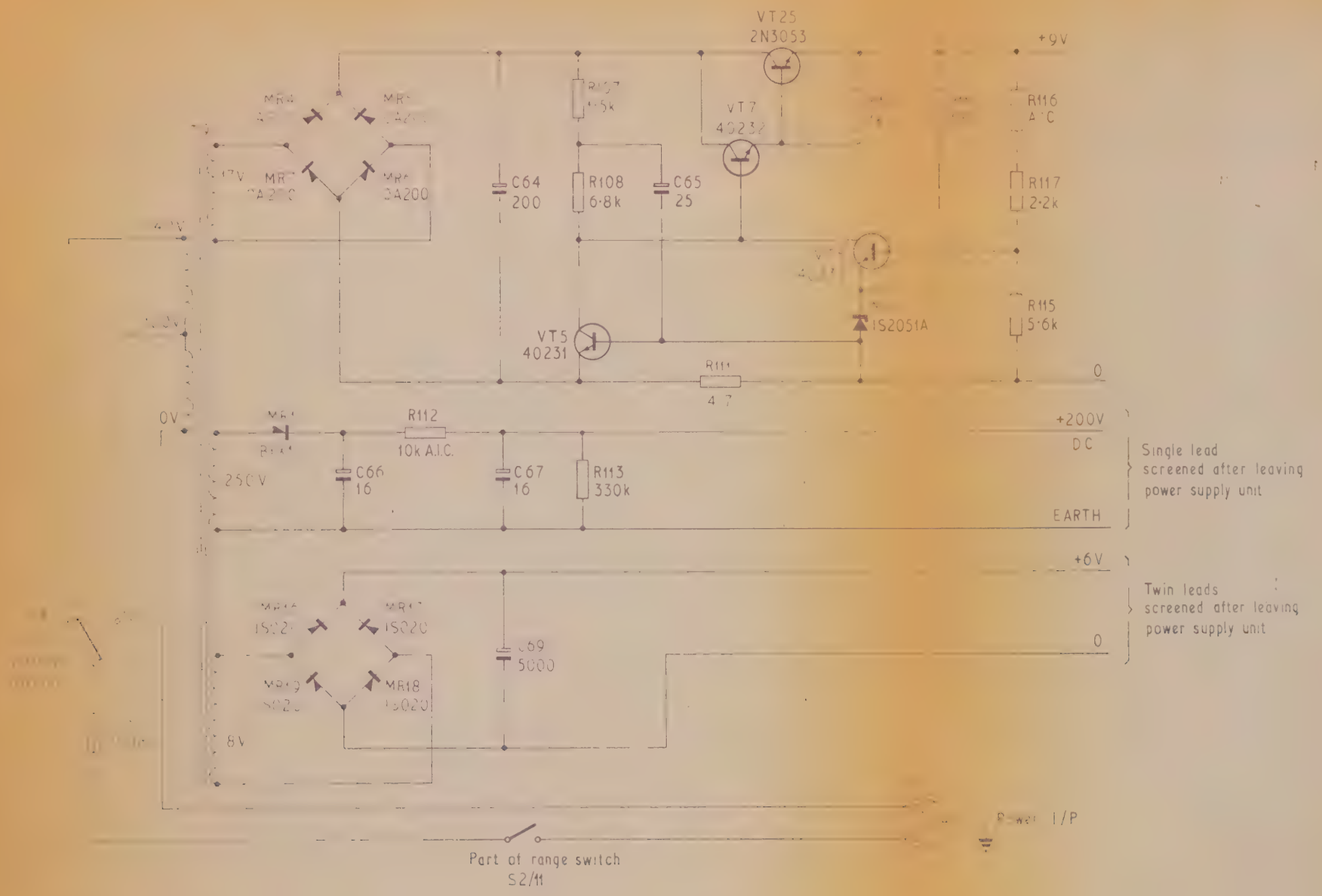
Power Supply Unit

59. The Power Supply Unit provides +9V d. c. with respect to ground for the main bridge circuits; +200V d. c. for the operation of the digital and decimal point indicator tubes and, finally, +6V d. c. to operate the range multiplier lamps. The lamps are operated from a d. c. supply to prevent the injection of 50Hz ripple into the bridge circuits. The operating principles of a series stabilizer circuit are too well known to require elaboration here. The circuit diagram of the Power Supply Unit is given in Fig. 22.

60. Overload Protection. The load current passes through R111 whose value is chosen so that if the current exceeds 100mA, the volt drop across R111 causes VT5 to commence conduction thus bleeding away the base current from VT7.



Range Multiplier Indicators Fig.21



Power Supply Circuit Fig.22

AUTOBALANCE PRECISION BRIDGE

B331

Maintenance Manual - Part 2

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(ILLUSTRATIONS for Part 2 are listed at the front of the book with those for Part 1)

PART 2

General

1 The following paragraphs give complete instructions for the adjustment of all the preset controls in the instrument. Where appropriate, tests are given to show up any departure from the original condition. Since these operations have a considerable bearing on the performance and accuracy of the instrument, it is essential that they should be performed only by skilled operators. A table of d. c. voltages is given but it is stressed that these are typical values and variations up to ±10% should not be regarded as serious. If extensive operations are to be performed, it is recommended that the capacitance standard C9 (ST25) be temporarily replaced by a suitably mounted good quality capacitor of approximately 25pF. A general view of the instrument is given in Fig. 23; this shows the hinged panels open for access to the interior. Figure 24 shows the instrument with the nucleus sub-unit dismounted.

2. The upper, middle and lower decades in both the C and G systems are known respectively as the first, second and third order decades. For convenience of notation, these are referred to in the following instructions as decades C1, C2, C3, G1, G2 and G3. Small roman letters following such a reference indicate separate switches operated by a particular button and, finally, the capital letter R or numerals 0, 1, 2..... etc. up to 10 signify the operated button (R indicates 'Reset'). For example, the reference G2a4 means switch 'a', button 4 on the middle, or second order G decade. If the reference is given as G2-4, it means that the particular switch is not significant.

****

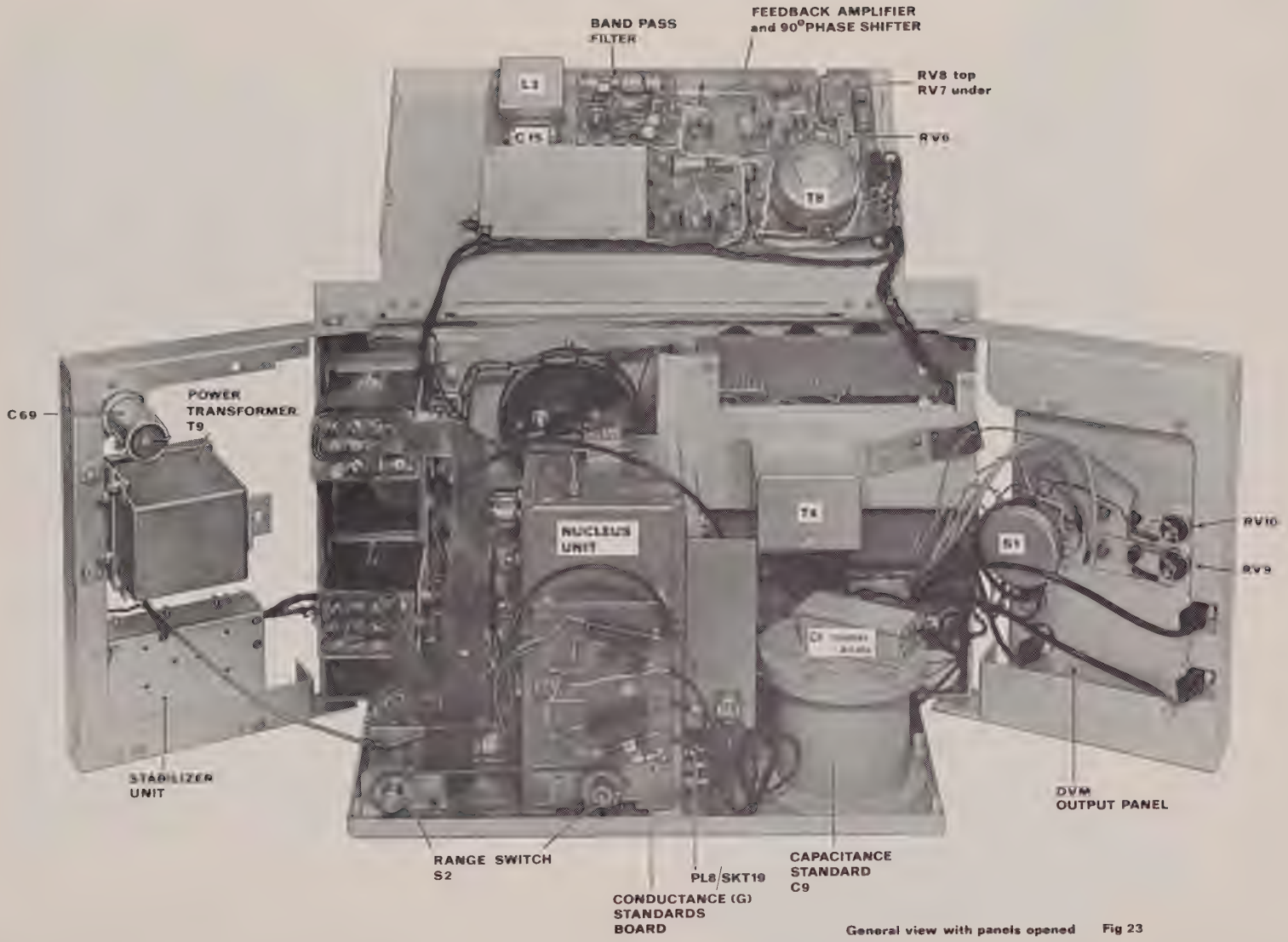
CAUTION

Although the electronic circuits in general operate from a 9-volt supply, there is a 200-250V d. c. supply to the digital indicator tubes. Due precautions should be taken when operating on or near these tubes.

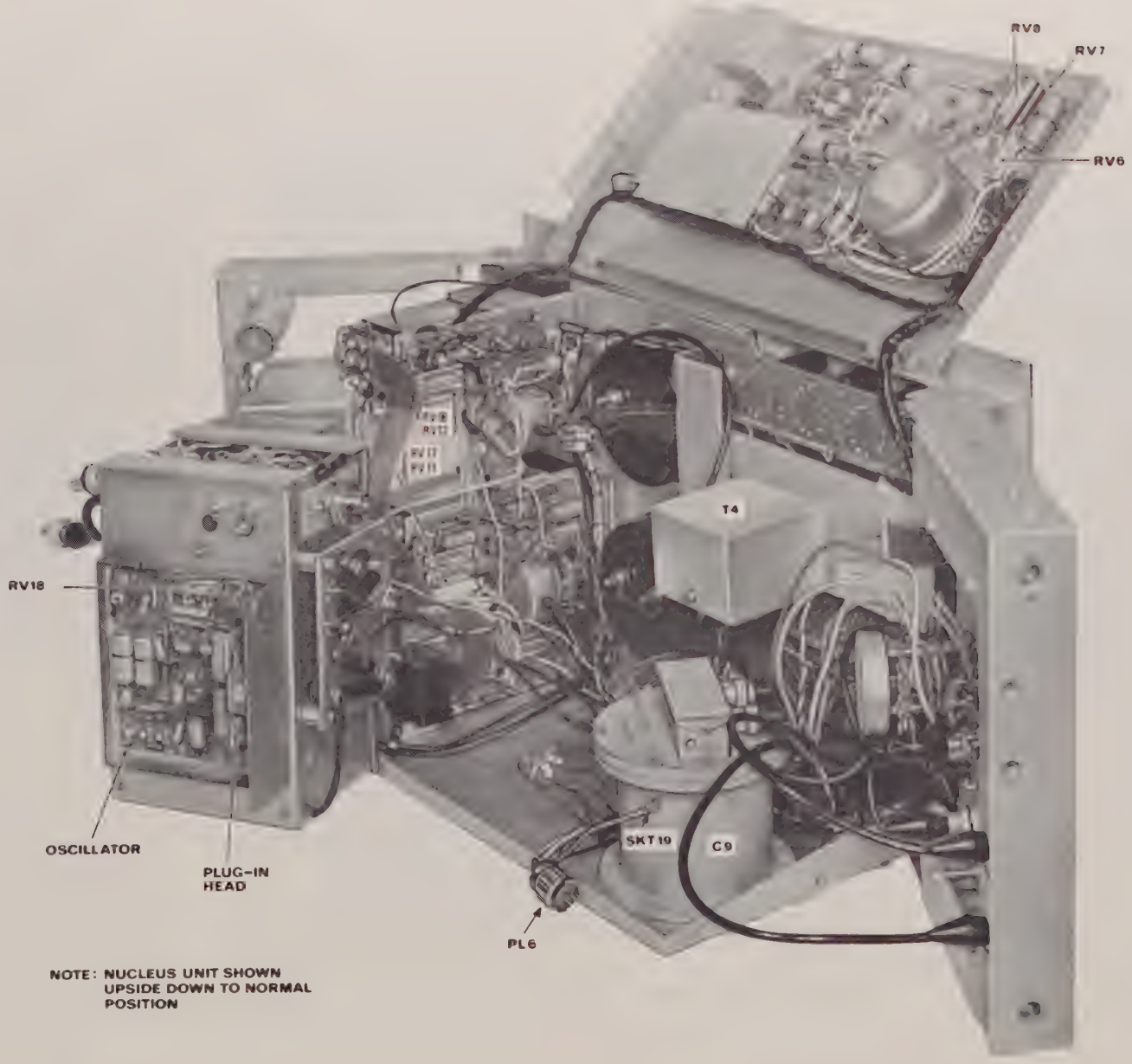
****

Preliminary Measurement Check

3 The following procedure affords a rapid check on the correct functioning of each range of the bridge. Using the Kelvin clip leads, connect a capacitor of value between 3 and 10pF as for a normal measurement. Since this is effectively a range check, the actual value of the component is immaterial;

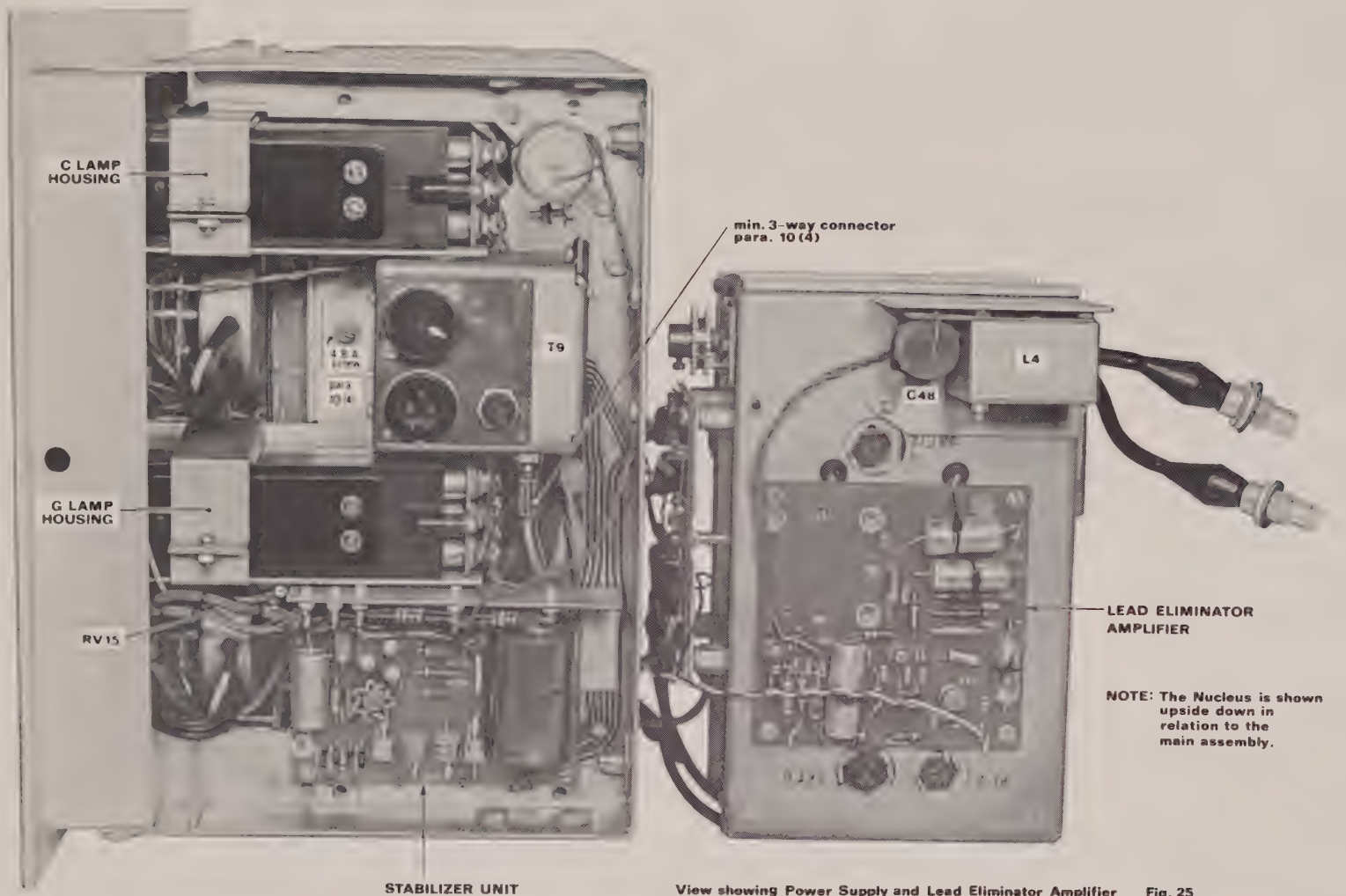


General view with panels opened Fig 23



NOTE: NUCLEUS UNIT SHOWN
UPSIDE DOWN TO NORMAL
POSITION

General view with Nucleus Dismounted Fig. 24



View showing Power Supply and Lead Eliminator Amplifier Fig. 25

also, the accuracy of the bridge trim is of little importance.

4 Set the Range switch to 8 and note that the value of the capacitance is indicated directly on the C meter. Move the range switch to 7 and press buttons C1-0 and G1-0; check that the meter indication is approximately as before. Move the Range switch to 6 and press buttons C2-0 and G2-0; the meter should again indicate approximately as before. Press all reset buttons and remove the capacitor.

5 Set the Range switch to 5 and connect a resistor of value between 10kΩ (100μMho) and 30kΩ. The conductance of this component should be indicated directly on the G meter. Move the Range switch to 4 and press buttons C1-0 and G1-0; check that the meter indication is approximately as before. Move the Range switch to 3 and press buttons C1-0 and G2-0; check that the meter again indicates approximately as before. Press all reset buttons and remove the resistor.

6 Set the Range switch to 2 and connect a 10Ω resistor (100mMho). Check that the meter indicates approximately 100mMho, i. e. approximately f. s. d. Move the Range switch to 1 (Low Impedance Range); the meter should now indicate the resistance value of the component, i. e., 10Ω (also f. s. d.).

Decade Push Button and Vernier Check

7 Decade Push Buttons. Set the Range switch to Calibrate and press all reset buttons. Press each C1 button in turn and check that the C meter indication corresponds with each digit pressed. Press the C1-R button. Repeat this procedure with the G1 decade, checking the indications on the G meter. Press buttons C1-0 and G1-0. Press each C2 button in turn and check the C meter indications as before. Press button C2-R and repeat the procedure for the G2 decade. Press buttons C2-0 and G2-0 (buttons C1-0 and G1-0 should remain pressed). Repeat the procedure for the C3 decade then press button C1-R. Finally, press button G3-1 and check that the G meter is at approximately f. s. d. Press all reset buttons.

8 Vernier Check. Press the G3-0 button. Carefully check the settings of the Trim C and G, Zero and FSD controls. Turn each Vernier control in turn from zero to maximum and check that the appropriate meter indication increases linearly to f. s. d. With the meter indication at f. s. d., turn the

appropriate polarity switch to '-' and check that the meter indication remains substantially unchanged. Return the polarity switches to '+', the Vernier controls to zero and press button G3-R.

Removal of the Case

9. To remove the instrument from the case, proceed as follows.

(1) Remove all plugs and the reciprocal tables from the side panels.

(2) Stand the instrument on its face, release the four quick-release fasteners on the rear panel and remove the cover.

(3) Stand the instrument on its feet. Loosen the four 2 B. A. Allen screws that secure the front handles (two per handle) sufficiently to allow the handles to be moved outwards until the lugs are clear of the front panel.

(4) Remove the two 2 B. A. cheese-head screws from each of four angle brackets at the rear corners of the frame assembly.

(5) Carefully withdraw the chassis assembly through the front of the case framework. In doing this, do not take the weight of the instrument on the top or bottom rails of the front panel as these are not secured after approximately 1/4-inch of forward movement of the chassis out of the frame.

10 To release the hinged panels.

(1) Remove the four 2 B. A. cheese-head screws (two on each side) that secure the top panel. The panel is then free to be raised when necessary.

(2) Remove the tie bracket that spans the rear of the two side panels. Two of the fastenings for this bracket are located on top of the nucleus unit and can be reached when the top panel is raised. These two screws each have two plain washers between the bracket and the top of the nucleus unit. All six screws have plain and crinkle washers under the heads. When reassembling, it is advisable to lower the top panel before finally securing the screws at each end of the tie bracket; this ensures that the top panel has sufficient clearance between the side panels. The top panel is then raised again to secure the screws on top of the nucleus.

(3) Remove the four 2 B. A. cheese-head screws that secure the DVM output panel. If operation 1 has been done, the top two screws will be already removed.

(4) Disconnect the miniature 3-way connector (see fig. 25) from the power

transformer. Remove the four 2 B. A. cheese-head screws from the top and bottom of the panel. Again, if operation 1 has been done, the top two screws will be already removed. Remove the 4 B. A. chesse-head screws from the power transformer bracket (see fig. 25).

Removal of the Nucleus Sub-Unit

11 Before removing the nucleus it is advisable to remove the Capacitance Standard C9 (ST25). This is secured by six 4 B. A. cheese-head screws through the bottom tray of the chassis assembly. After removing C9, proceed as follows.

(1) Disconnect the plug and socket connectors from the nucleus - two on top and two on each side and the rear panel.

(2) Locate the black chassis connection from the oscillator panel (right-hand side as viewed from the rear) and unsolder this from the 6-way chassis tag. Remove the 6 B. A. nut from the stud at the centre of the tag and withdraw the tag, leaving the remaining wires connected.

(3) Remove the 6 B. A. cheese-head screw that secures the cleat round the two cables to the left-hand side of the Standards board.

(4) Remove the front nuts that secure the two B. N. C. triaxial connectors (E and I Unknown) to the front panel. Take care not to damage the plastic front of the panel.

(5) Remove the four 4 B. A. cheese-head screws, plain and crinkle washers that secure the base of the nucleus to the bottom panel of the chassis assembly. Slide the nucleus slightly to the left until the Range switch drive belt can be slipped over the gear pulleys. Push the B. N. C. triaxial connectors through the front panel, then carefully move the nucleus to the right and rearwards until the ninth connector (on the face of the nucleus adjacent to the front panel) can be disengaged. Carefully lift the nucleus away from the main assembly.

NOTE: (1) If it is necessary to separate the Nucleus completely from the main assembly, the five screened leads to the Standards Board must be disconnected.

(2) The E and I Unknown sockets are insulated from the chassis by means of moulded washers. When reassembling, note that each washer has a locating pip on one side and this should face outwards when the washer is

placed on the socket prior to feeding the socket through the aperture in the front panel. Ensure that the pip is correctly located before tightening the nuts on the front of the sockets. It is imperative that these washers are fitted since they prevent the connectors from rotating; also, in the case of the I socket, the outer shell is isolated from the chassis (see fig. 5).

12 It is possible and, for some operations, convenient to operate the instrument with the nucleus unit outside the main assembly. However, to do this a number of jumper cables are necessary; these comprise the following pairs of connectors joined together to form cables approximately 12 inches long.

(a) PL7 (Amphenol Type 27-10) to SKT18 (Amphenol Type 27-7)

(b) PL8 (Amphenol Type 27-10) to SKT19 (Amphenol Type 27-7)

(c) PL9 (Cannon Type DA 15P) to Film Wiring (2nd order C decade) (Cannon Type DA 15S)

(d) SKT11 (Amphenol Type 126-218) to PL3 (Amphenol Type 126-217)

(e) SKT12 (Amphenol Type 126-215) to PL4 (Amphenol Type 126-214)

(f) SKT14 (Amphenol Type 126-221) to PL6 (Amphenol Type 126-220)

(g) SKT15 (Cannon Type DA 15S) to Film Wiring 1st. order C decade (Cannon Type DA 15P)

(h) SKT16 (Cannon Type DA 15S) to Film Wiring - G decade - (Cannon Type DA 51P)

The connector that mates with PL2 in the nucleus unit (SKT9) can be connected without a jumper cable when the sub-unit is dismounted. For reference, the connectors are: PL2 - Amphenol Type 126-214; SKT9 - Amphenol Type 126-215.

13 The section of the Range switch contained in the nucleus unit is not operated by the front panel control when the nucleus is dismounted. Separate provision must therefore be made to operate the dismounted part of the switch. For example, temporary index marks can be made on the chassis and the gear pulley but note that clockwise rotation of the front panel control must be accompanied by an equal counter-clockwise rotation of the gear pulley.

SETTING-UP INSTRUCTIONS

Test Equipment Required

14 The following items of test equipment are required for the calibration of the instrument. Miscellaneous components, used in some tests, are detailed in the appropriate paragraphs.

(1)	Timer Counter	Racal Type SA535
(2)	Double Beam Oscilloscope	Telequipment D43 with Amplifier
(3)	Multimeter: 20 000Ω/V	AVO 8
(4)	Millivoltmeter	Comark Type 120
(5)	Digital Voltmeter 200mV	Digitec model 402
(6)	Standards (see next sheet)	

Other test equipment of equivalent specification can be used.

9V Supply

15 Before commencing any tests or adjustments, check the +9V supply by connecting a multimeter (10V d. c. range) and an oscilloscope between chassis (-) and any convenient point in the +9V line. The voltage should be between 8. 8 and 9. 2V; the ripple should not exceed 10mV pk-pk.

Oscillator Frequency Adjustment

16 On some models, frequency adjustment is by means of a trimmer capacitor C60 while on others the adjustment is by means of a variable resistor RV18. In either case, the A. I. C. capacitor C61 may or may not be fitted; if it is not, accommodation for it is provided in case it becomes necessary after servicing. Figure 26 shows the Wien bridge plug-in head upon which are mounted the frequency determining components. When RV18 is fitted instead of C60, RV18 is mounted on the main oscillator p-c board as shown in Fig. 24.

17 To check the oscillator frequency, remove the outer cover - see para. 9, operation 1 - and connect the input terminals of the Timer Counter (para. 14, item 1) to the E_{10} socket of the Offset Winding behind the left-hand door. The frequency should be 1591. 55Hz nominal; if necessary, adjust the frequency by means of C60 or RV18 whichever is fitted. If the A. I. C. capacitor is to be fitted or replaced, its value should not exceed 100pF, this value giving a frequency change of 5Hz and pro rata.

18 Although no provision is made for the adjustment of the oscillator output

[14] (6) Conductance standards as follows: 100mMho (10Ω), 10mMho (100Ω), 1mMho (1kΩ), 100μMho (10kΩ), 10μMho (100kΩ). All are Alma Type JF3/2Z Tolerance ±0.01%.

Capacitance standards as follows:

10pF	Wayne Kerr Type ST10
100pF	General Radio Type 1404-9702
1000pF	General Radio Type 1404-9701

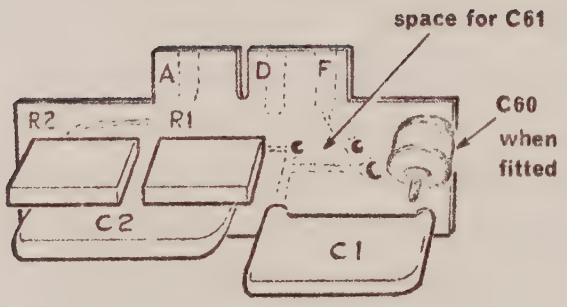


Fig. 26 Wien Bridge Plug-in Head

level, a knowledge of its value may be useful in fault diagnosis. An oscilloscope connected to the E_{10} socket should show a clean sinewave of approximately 1 to 1.5 volts peak-to-peak amplitude.

Setting-up the Calibration Controls

19 Set the Range switch to Calibrate and press the decade button G3-0. Adjust the Trim C and Trim G controls for zero indication on both meters. Press button C3-1 and adjust the control F.S.D. until the C meter is at f.s.d. If the control has insufficient range, the value of R95 may be increased to 68kΩ. Adjust the Zero control for zero indication on the G meter. Repeat if necessary. Press buttons C3-0 and G3-1. Adjust potentiometer RV8 until the G meter reaches f.s.d. Adjust potentiometer RV7 for zero indication on the C meter.

Feedback Amplifier

20 The tuning of the feedback amplifier requires only the removal of the outer cover - see para. 9, operation 1. However, if the further checks on the amplifier are to be made, it may be more convenient to raise the amplifier panel - see para. 9 and 10(1). Set the Range switch to Calibrate, both Vernier controls to zero and press the reset buttons (red) on all decades. Disconnect the feedback lead at plug PL8 on the nucleus unit. Trim the bridge very carefully; note that in the absence of feedback, considerable meter interaction will occur. Turn the G Vernier control clockwise to give approximately 20% G meter deflection.

21 Adjust the core of L3 for maximum indication on the G meter, adjusting the setting of the G Vernier as required. Access to the core of L3 (see Fig. 23) is through a hole at the right-hand side of the top hinged panel. When L3 is peaked, adjust the G Vernier to give f.s.d. on the G meter; check that the C meter indication is not more than 20% f.s.d. If it is, de-tune L3 just sufficiently to meet this condition.

22 Return the G Vernier to zero (fully counter-clockwise); check and, if necessary, readjust the bridge trim. Press button G3-0 and again check the bridge trim. With the oscilloscope connected to the amplifier output at C26, check that the residual signal, together with the noise and hum, does not exceed 1V pk-pk. Move the oscilloscope connection to the output

of the bandpass filter. Set the G Vernier to give f. s. d. on the G meter; check that the Vernier setting is not greater than 030 and that the oscilloscope indicates approximately 2. 0V pk-pk. Set the G Vernier to achieve maximum output without clipping; this output should be not less than 4. 0V pk-pk.

23 The correct functioning of the open-loop gain switching (emitter circuit of VT10) can be checked as follows. Set both Vernier controls to zero and engage the 0 button on all decades. Carefully trim the bridge. Set the G Vernier to achieve f. s. d. on the G meter; note the setting of the G Vernier. Press buttons C3-R and G3-R, check that the G meter indication remains substantially unaltered. Press buttons C2-R and G2-R, note that the G meter indication falls. Reset the G Vernier to restore the G meter to f. s. d. and check that the new setting of the vernier is approximately ten-times that of the previous setting. Press buttons C1-R and G1-R; check that the G meter indication falls to approximately 10% f. s. d.

24 The correct functioning of the amplifier feedback switching (i. e. the closed-loop gain) can be checked as follows. Turn RV6 fully clockwise; the wiper should then be at the end remote from the terminations (when the hinged panel is raised, the wiper can be seen through the transparent case of the component). Reconnect the feedback at PL8 on the nucleus unit. Press the button C1-0 and the reset button on all other decades. Check that the C meter indication is zero. Press button C1-10 and adjust the FSD control for f. s. d. on the C meter. Adjust the Zero control for zero indication on the G meter. Press buttons C1-0 and G1-0; check the bridge trim and then press button C2-10. The C meter should indicate f. s. d. ± 0.5% (i. e. ± 1/2 small division). The G meter should indicate zero ±0.5%. Press buttons C2-0 and G2-0; check and adjust the bridge trim, then press button C3-10 and check that the C meter indicates f. s. d. ±0.5% and the G meter indicates zero ±0.5%. Press buttons C3-0 and G3-0, check the trim and then press button C3-1. The C meter should indicate f. s. d. +0, -5%. The G meter should indicate zero ±5%. If the G meter indication differs from zero by a significant amount (but not more than 5%), it is permissible to make a small correction by altering the amplifier tuning - not more than three turns of the core - in such a direction as to correct the phase

error. If necessary, adjust RV6 to achieve exactly f. s. d. on the C meter.

Lead Eliminator Amplifier

25 Tuning Check. Connect a resistor of value 100Ω (any type and tolerance) in series with another of value 10Ω; the latter must be a carbon or metal film type. With the bridge set to Range 3 and using the low impedance leads (Reference D15466), trim the bridge and then connect the various clips to the 100Ω resistor as for a normal measurement (see Operating Instructions). Balance the bridge on all decades and note the full G value very carefully. Now move the appropriate red lead from the junction of the two resistors to the free end of the 10Ω resistor, leaving the other red lead and both black leads (lead eliminator) unaltered. Any change in G value from that previously noted signifies mistuning of the lead eliminator amplifier. If this is the case, correct the tuning by adjusting the core of inductor L4 until the two G values (as described above) are identical.

26 Gain Check. Connect two resistors of value 10Ω and 1Ω in series. These should be high stability ±5% components. With the instrument set to Range 2 and using the procedure described above, measure the 10Ω resistor; note the G value. Move the appropriate red lead to the free end of the 1Ω resistor (i. e. the lead resistance is effectively increased by 1Ω) and re-balance the bridge; note the new G value. The gain of the lead eliminator amplifier is given by

$$\text{L/E gain} = \frac{10}{\%\ \text{change in G value}}$$

The figure thus obtained should not be less than 270. Repeat the measurement on Range 3 using 100Ω and 10Ω resistors, and again on Range 4 using 1000Ω and 100Ω resistors. The gain should not be less than 210 and 65 respectively.

Setting-up the Conductance Standards

27 Set the Range switch to 5 and trim the bridge as accurately as possible. Using the Kelvin clip leads, connect the external 100μMho standard to the bridge. Balance the bridge on all decades of C and G. If the polarity switch is altered the bridge must be re-trimmed. Note the G value as

indicated on the bridge and compare this with the stated value of the standard. It is convenient to make this comparison in terms of parts per million (p. p. m.) because when button G1-10 is engaged, one small meter division (1% of f. s. d.) is equivalent to 10 p. p. m. Thus, if the G value is set up as 10, 0, 0 on the decades and, nominally, zero on the meter (rather than 9, 9, 9 on the decades and 10 on the meter), any departure from the nominal can be read directly from the meter in terms of parts per million. Also, since the accuracy of the decades is inherently greater than that of the meter, it is better to have as much as possible of the value on the decades.

28 The internal major conductance standard (R22) is adjusted, if necessary, by adding low value resistors in series with it (provision is made for this on the Standards Board - see fig. 23) to the extent of 1Ω for every 100p.p.m. error. Note that the tolerance of R22 is always negative. At this stage, the value of the standard, R22, should be adjusted only to the nearest 50p. p. m. (i. e. to the nearest 0.5Ω) and the padding resistors should be soldered in place temporarily. Press all reset buttons.

29 Set the Range switch to 6 and carefully trim the bridge. Connect the 10μMho external standard and balance the bridge fully on both C and G; record the values. Repeat this procedure on Ranges 3 and 4, using 10mMho and 1mMho standards respectively.

30 Change the bridge leads for the Low Impedance leads (D15466), set the Range switch to 2 and carefully trim the bridge. Connect the 100mMho external standard to the bridge, balance completely and record the G value. This value must be corrected to take account of the lead resistance. The resistance of the Low Impedance leads is 20mΩ each but this must be divided by the improvement factor given by the lead eliminator system. This improvement factor is equal to the lead eliminator gain as measured in para. 26. Suppose this figure to be 100, then the effective lead resistance is

$$\frac{2 \times 20\ m\Omega}{100} = 0.4m\Omega$$

and 0.4mΩ in 10Ω is equivalent to 40p. p. m. Thus 40p. p. m. (or whatever

figure is obtained, depending on the L/E gain of the particular instrument) must be added to the G value noted at the beginning of this paragraph.

31 Examine the recorded G values and note the spread of the errors (i. e. the difference between the greatest negative and the greatest positive). If this is less than 140p. p. m. proceed to the next paragraph; if more than 140p. p. m. proceed as follows. Connect a resistor of value between 200Ω and 500Ω (±10% any type) between the stand-off terminals on the nucleus below PL8 (see fig. 24). This resistor loads the 4-turn winding of T7 and makes the error on Ranges 2, 3 and 4 more negative. If it proves necessary to fit the resistor, the five measurements previously made must be repeated.

32 Determine the mean error between the greatest positive and the greatest negative errors. Return to Range 5 and adjust the value of R22 (as described in para. 27 and 28) until the mean error over Ranges 2, 3, 4 and 5 is zero or as near to it as possible.

33 Leaving the 100μMho external standard connected to the bridge, balance the bridge first with buttons G1-9 and G2-10 pressed, and then with buttons G1-10 and G2-0 pressed. Compare the G meter indication in each case; the difference between the two indications should be not greater than one minor division. If this is not the case, adjust the internal G2 standard (R23) by adding series resistors at the rate of 10Ω per 100p. p. m. error until the condition is satisfied.

34 Press buttons G2-9 and G3-10; check that the G meter indication is within one minor division of that obtained in the previous paragraph. If not, adjust the value of the G3 standard (R24) in the same way until the condition is met.

35 Press button G3-9 and set the G Vernier to 10. Check that the G meter indication is within one minor division of that obtained in para. 33. If not, adjust the Vernier standard (R25) until the condition is met. Return the Vernier control to zero.

Elimination of Capacitance of the G Standard

36 With the bridge set to Range 5 and the measurement leads in place, carefully trim the bridge. Connect a carbon or metal film resistor of

value 10kΩ (tolerance not important) to the measurement leads and balance the bridge on all decades.

37 Note the C meter indication and adjust the trimmer capacitor C12 (on the Standards Board, see fig. 23) until this is reduced to +0.3pF - this being the capacitance between the ends of a typical RC7-K style resistor. If necessary, a fixed polystyrene capacitor of not more than 5pF may be added in parallel with the trimmer C12.

Setting-Up the Capacitance Standard

38 Set the Range switch to 8. Connect the precision 10pF standard capacitor to the Unknown sockets. If the Wayne Kerr Standard Capacitor Type ST10 is used it must be connected by means of Triaxial-to-B. N. C. coaxial adaptors; in this case, the bridge must be trimmed with the adaptors in place. With the bridge fully balanced, record the C and G values.

39 Set the Range switch to 7 and measure the C and G values of the 100pF standard capacitor. Compare these results, and those of the previous measurement, with the absolute values as stated for the external standards. If the error in the measured C values is greater than 70p. p. m., adjust the trimmer on the top of C9 (see fig. 23) until the mean error is as near to zero as possible; repeat the tests.

40 With the 100pF external standard capacitor connected and the bridge fully balanced, check that the three C decade combinations (i. e. buttons 10-0-0 or 9-10-0 or 9-9-10) all give the same result.

41 Press button 9 on all three C decades and set the C Vernier to 10. The C meter indication should be exactly as before; if necessary, adjust RV15 to meet this condition. Potentiometer RV15 is located under the G range display lamp housing (see fig. 25).

Setting-Up the D. V. M. Outputs

42 The following procedure is identical for both the C and G D. V. M. outputs. Component references are given for the C system, the corresponding G components being added in parentheses. Connect the digital voltmeter (100mV range) to the C DVM (G DVM) output. Set the instrument controls as for calibration and press button G3-0.

43 The preset potentiometer RV12 (RV11) - see fig. 24 - must be adjusted until the digital voltmeter indicates zero, but first check that the control has enough latitude to take up any drift in the zero. Check that the control can be set to give at least 3mV on each side of zero before finally setting to zero.

44 Press the button C3-1 and adjust either the FSD control or the C Vernier (G Vernier) until the C meter (G meter) indicates exactly f. s. d. Set the DVM Output control RV10 (RV9) on the side panel to its maximum clockwise position. Connect a 100kΩ ± 1% resistor across the digital voltmeter input terminals. Adjust RV16 (RV17) and the FSD control (or the appropriate vernier) together until the digital voltmeter indicates approximately 105mV.

45 Disconnect one side of the 100kΩ resistor and turn RV10 (RV9) to its maximum counter-clockwise position. Check that the digital voltmeter indication is less than 100mV. Adjust the setting of RV16 (RV17) by trial and error until a position is found such that the maximum output into the 100kΩ load is approximately as much above 100mV as the minimum output into no load is below 100mV. Finally, adjust RV10 (RV9) to give 100mV across the 100kΩ load and then repeat the Calibration procedure given in para. 19.

Nucleus Unit

46 There are no preset controls or adjustments in the nucleus unit and it should not in any circumstances be dismantled. However, the following tests will serve as a guide to its serviceability. When making connection to individual pins of plugs and sockets, it is advisable to use a mating connector to which short lengths of wire are attached. It is assumed that the Nucleus is in position in the main assembly.

47 Remove the mating connectors from SKT15, PL9, PL2, PL7, PL8, SKT11 and SKT12. Disconnect the screened lead from the right-hand side of R22 on the Standards Board (see fig. 23).

48 Connect the AF Oscillator output to pin 11 of SKT15. Set the oscillator frequency to 1kHz and its output level to 3V rms. Check this level with the valve voltmeter and then connect the v. v. m. to the inner screen of

the E Unknown socket (i. e. to the rotor of S2/1 in fig. 5). Rotate the Range switch and check that the indicated voltages are as tabulated below. Disconnect the v. v. m.

Range	Voltage r. m. s.
8	3. 0V
7	1. 0V
6	300mV
5	100mV
4	30mV
3	10mV
2	3mV
1	300mV

49 Connect one beam of the oscilloscope between the Unknown E inner and chassis, and the other beam between the E inner screen and chassis (i. e. to the rotors of S2/1 and S2/2 in fig. 5). Connect together pins A and B on the Lead Eliminator Amplifier Board (top rear corner of the board - see fig. 25). Set the output level of the AF Oscillator to 30V pk-pk. Set the Range switch to ranges 2, 3 and 4 in turn and check that on each range the two displayed waveforms are equal in amplitude and that they are in phase. Remove the short circuit from pins A and B on the L/E amplifier board.

50 Connect one beam of the oscilloscope to the output from the AF Oscillator and let this be the reference signal (the oscillator output remains connected to pin 11 of SKT15). Connect the other beam to pin A of PL2 and check that this signal is in phase with, and one-tenth of the amplitude of the reference signal. Transfer this beam of the oscilloscope to pin C of PL2 and check that the signal is in anti-phase with, and one-tenth of the amplitude of the reference signal. Similarly, check that the signal at pin D of PL2 is in phase with, and 1/300 of the amplitude of the reference signal.

51 Set the output level of the AF Oscillator to 3V rms. Using the valve voltmeter, check that the amplitude of the voltage at the pins of PL9, SKT15 and SKT16 conforms with the following table. To check the voltages on SKT16 connect the v. v. m. to the screened lead that was

removed from R22 in para. 47; press in turn the buttons 0 to 10 on decade G1 and read the voltage.

PL9		SKT15		SKT16	
Pin	Voltage	Pin	Voltage	Pin	Voltage
8	0	8	0	11	0
7	30mV	7	300mV	10	10mV
6	60mV	6	600mV	9	20mV
5	90mV	5	900mV	1	30mV
4	120mV	4	1.2V	2	40mV
3	150mV	3	1.5V	3	50mV
2	180mV	2	1.8V	4	60mV
1	210mV	1	2.1V	5	70mV
9	240mV	9	2.4V	6	80mV
10	270mV	10	2.7V	7	90mV
11	300mV	11	3.0V	8	100mV
12	330mV	12	3.3V		

52 Connect the AF Oscillator output to PL7. Use one beam of the oscilloscope to set the oscillator output to 1V pk-pk; let this be the reference signal. Using the other beam, check that the waveform at PL8 is equal in amplitude but opposite in phase to that at PL7 (reference signal).

53 Connect the valve voltmeter in parallel with the reference signal at PL7 and set the AF Oscillator output level to 2.0V rms. Transfer the v. v. m. to the other beam of the oscilloscope and check as follows.

Check Point	Voltage rms	Phase w. r. t. Reference
SKT11 Pin H to Pin A	3.2V	in phase
SKT11 Pin H to Pin B	3.2V	in anti-phase
SKT12 Pin B to Pin C	240mV	in phase
SKT12 Pin B to Pin A	240mV	in anti-phase

54 Leave the input to PL7 as in the previous paragraph. Connect the oscilloscope and the valve voltmeter between the I inner screen and the I outer screen (earthy). Check that the voltage is in anti-phase with the reference signal and that its amplitude is in accordance with the following table.

Range	Voltage rms
8	8.0V
7	2.4V
6	800mV
5	240mV
4	80mV
3	24mV
2	8mV

Re-connect the v. v. m. between the E inner (earthy) and the I inner, and check that on Range 1 a voltage of 800mV is registered.

Disconnect all test equipment and reconnect the screened lead to R22.

Replacement of the Digital Indicator Tubes

55 If a digit fails to energize on any of the digital indicator tubes, the cause could be either a faulty switch contact or an unserviceable tube. To ascertain the correct cause, connect one end of a crocodile clip lead to the chassis and the other end (via a prod or screwdriver blade) to the appropriate tube contact (see table below). If the digit is then energized, a switch fault is indicated and the instrument should be returned to the factory for repair. If, however, the digit still fails to energize, the tube can be replaced as described below; this procedure applies only to instruments up to Serial Number 125. The procedure for later models is given in the appendix covering these instruments.

PIN CONNECTIONS FOR INDICATOR TUBES GN-4 OR GR10M

Pin. No.	1	2	3	4	5	6	7	8	9	10	11	12	13
Electrode	-	Anode	0	9	8	7	6	-	5	4	3	2	1

As viewed from the base, the pins are numbered in a clockwise direction from the gap.

56 To replace a digital indicator tube, proceed as follows.

(1) Remove the instrument from its case - see para. 9.

(2) Open the top hinged panel and the DVM Output panel - see para. 10.

(3) Remove the three 4 B. A. cheese-head screws that secure the decade switch screening plate. This plate incorporates the screen for transformer T4 (see fig. 23 and 24).

(4) C Indicator tubes only. Remove the tapped metal spacer, crinkle washer and nylon spacer from the 4 B. A. stud at each end of the tube p-c board.

G Indicator tubes only. Remove the 4 B. A. nut, crinkle washer and nylon spacer from the 4 B. A. stud at each end of the tube p-c board.

(5) Very carefully ease the p-c board off the studs and then tilt it until the defective tube can be removed from its holder. The p-c board will

be restrained to some extent by the film tape wiring and the greatest care must be exercised throughout the operation to avoid damage.

(6) Transfer the moulded rubber hood from the old to the new tube, insert the tube in its holder and re-assemble the instrument by reversing the preceding operations.

DC Voltages

57 The d. c. voltages given below are typical values for guidance only, deviations of up to 10% from these values can be regarded as normal. The measurements are made with the Range switch set to Calibrate and with the bridge trimmed. The measuring instrument used is the Comark D. C. Millivoltmeter Type 120S. Values are volts except VT13 emitter.

Oscillator

	Collector	Base	Emitter
VT1	5.3	4.13	3.53
VT2	6.93	5.3	4.68
VT3	9.0	4.0	3.33
VT4	9.0	4.0	3.33
VT26	3.33	1.7	1.03

Feedback Amplifier

	Collector	Base	Emitter
VT8	1.15	0.56	0
VT9	7.1	1.15	0.57
VT10	2.85	1.3	0.68
VT11	4.9	2.85	2.16
VT12	7.7	4.9	4.2
VT29	7.0	1.9	1.3

90° Phase Shifter

	Collector	Base	Emitter
VT13	3.85	0.58	6.8mV
VT14	7.2	3.85	3.2
VT21	7.9	7.2	5.3
Junction R52/R48	0.55		

LIST OF COMPONENTS

When ordering spare parts, please quote the Instrument Type and Serial Numbers, and the circuit reference and value of the required component.

Resistors, fixed

Cct. Ref.	Description		Style or Supplier and Type
R1	7.5k	0.05%	Welwyn Vishay Type 4804
R2	15k	0.05%	" " " "
R3	470	10%	RC7-K
R4	2.7k	10%	RC7-K
R5	3.3k	10%	RC7-K
R6	330	10%	RC7-K
R7	470	10%	RC7-K
R8	4.7k	10%	RC7-K
R9	180	10%	S. T. C. Silistor 502K/181/RY/1
R10	4.7k	10%	RC7-K
R11	470	10%	RC7-K
R12	180	10%	RC7-K
R13	2.7k	10%	RC7-K
R14	100k	10%	RC7-K
R15	3.9k	10%	RC7-K
R16	12k	10%	RC7-K
R17	12k	10%	RC7-K
R18	2.2k	10%	RC7-K
R19	39	10%	RC7-K
R20	4.7k	1%	RC2-E
R21	1M	1%	RC2-E
R22	9995	0.01%	Alma Type JC2Z
R23	99950	0.01%	Alma Type JC2Z
R24	999500	0.1%	Alma Type MA1
R25	999500	0.1%	Alma Type MA1
R26	2.2k	10%	RC7-K
R27	15k	5%	RC2-E
R28	68k	10%	RC7-K
R29	680	10%	RC7-K
R30	220	10%	RC7-K
R31	1k	10%	RC7-K
R32	47	5%	RC2-E
R33	2.2k	10%	RC7-K
R34	560	5%	RC2-E
R35	12k	10%	RC7-K

Cct. Ref.	Description		Style or Supplier and Type
R36	10	5%	RC2-E
R37	100	5%	RC2-E
R38	1k	5%	RC2-E
R39	180k	10%	RC7-K
R40	1k	10%	RC7-K
R41	10	5%	RC2-E
R42	330	5%	RC2-E
R43	1k	5%	RC2-E
R44	10k	5%	RC2-E
R45	680	10%	RC7-K
R46	1k	10%	RC7-K
R47	10k	1%	RC2-E
R48	10k	10%	RC7-K
R49	22	10%	RC7-K
R50	12k	10%	RC7-K
R51	1k	10%	RC7-K
R52	1k	10%	RC7-K
R53	270	10%	RC7-K
R54	1.5k	5%	RC2-E
R55	47k	10%	RC7-K
R56	1.8k	10%	RC7-K
R57	1.8k	10%	RC7-K
R58	33k	10%	RC7-K
R59	33k	10%	RC7-K
R60	47k	10%	RC7-K
R61	2.7k	10%	RC7-K
R62	2.7k	10%	RC7-K
R63	12k	10%	RC7-K
R64	12k	10%	RC7-K
R65	12k	10%	RC7-K
R66	4.7k	10%	RC7-K
R67	2.2k	10%	RC7-K
R68	2.2k	10%	RC7-K
R69	4.7k	10%	RC7-K
R70	12k	10%	RC7-K
R71	4.7k	10%	RC7-K
R72	4.7k	10%	RC7-K
R73	2.2k	10%	RC7-K
R74	2.2k	10%	RC7-K
R75	2.2k	10%	RC7-K
R76	15k	10%	RC7-K
R77	15k	10%	RC7-K
R78	100k	1%	RC2-E
R79	100k	1%	RC2-E
R80	2.2k	10%	RC7-K

Cct. Ref	Description		Style or Supplier and Type
R81	100k	10%	RC7-K
R82	3. 3k	10%	RC7-K
R83	100	10%	RC7-K
R84	56k	10%	RC7-K
R85	100k	10%	RC7-K
R86	2. 2k	10%	RC7-K
R87	10k	5%	RC2-E
R88	1k	5%	RC2-E
R89	68	5%	RC2-E
R90	1. 5k	10%	RC7-K
R91	560	10%	RC7-K
R92	1k	+0 -0.1%	Alma MA 1/4
R93	1k	+0 -0.1%	Alma MA 1/4
R94	62k	5%	RC2-E
R95	62k	5%	RC2-E
R96	910	5%	Radio Spares Metal Oxide
R97	910	5%	" " " "
R98	470	10%	RC7-K
R99	2. 7k	10%	RC7-K
R100	15k	10%	RC7-K
R101	47	10%	RC7-K
R102	100k	1%	RC2-D
R103	100k	1%	RC2-D
R104	3. 3k	5%	RC2-E
R105	3. 3k	5%	RC2-E
R106	100	10%	RC7-H
R107	1. 5k	10%	RC7-K
R108	6. 8k	10%	RC7-K
R109	1. 0k	10%	RC7-K
R110	680	10%	RC7-K
R111	4. 7	10%	RC7-K
R112	5k	5% 3W	Welwyn Type AW3101
R113	230k	10%	RC7-K
R114	Not Used		
R115	5. 6k	10%	RC7-K
R116	A. I. C.	10%	RC7-K 470 to 1. 5k
R117	2. 2k	10%	RC7-K
R118	39k	10%	RC7-K
R119	39k	10%	RC7-K
R120	39k	10%	RC7-K

Cct. Ref.	Description		Style or Supplier and Type
R121			
R122			
R123	39k	10%	RC7-K
R124			
R125			
R126			
R127			
R128	150k	10%	RC7-K
R129			
R130			
R131			
R132	3.9Ω	1/2W	Radio Spares 'Low Ohm'
R133	18k	5%	Radio Resistor Type LG 75
R134	82k	10%	RC7-K
R135	100k	10%	RC7-K
R136	100k	10%	RC7-K
R137	39k	10% 2W	Radio Resistor Type 0
R138	82k	10% 1W	RC7-H
R139	Not Used		
R140	100k	1%	RC2-E
R141	100k	1%	RC2-E
R142	100	10%	RC7-K
R143	1.8k	10%	RC7-K
R144	100k	10%	RC7-K
R145	100k	10%	RC7-K
R146	100k	10%	RC7-K
R147	100k	10%	RC7-K
R148	10k	10%	RC7-K
R149	Not Used		
R150	3.9Ω	1/2W	Radio Spares 'Low Ohm'
R151	3.9Ω	1/2W	Radio Spares 'Low Ohm'
R152	3.9Ω	1/2W	" " " "
R153	Not Used		
R154	Not Used		
R155	180	10%	RC7-K
R156	18k	1%	Electrosyl Type TR5
R157	47k	1%	" " "
R158	180k	1%	" " "
R159	3.9k	1%	" " "
R160	15k	1%	" " "

Cct. Ref	Description		Style or Supplier and Type
R161	15k	1%	Electrosyl Type TR5
R162	270k	1%	" " "
R163	270k	1%	" " "
R164	1.5k	1%	" " "
R165	100	10%	RC7-K
R166	120	10%	RC7-K
R167	3.9k	10%	RC7-K
R168	82	10%	RC7-K

Resistors Variable

RV1	Not Used		
RV2	1k	3-turn helipot	Bourns 3510S-71-102
RV3	1k	"	" "
RV4	1k	10-turn helipot	Bourns 3600S-1-102 (Knobpot)
RV5	1k	"	" " "
RV6	100	10% W-W	Reliance Type WL35 P.C.
RV7	1k	10% W-W	" " "
RV8	1k	10% W-W	" " "
RV9	20k	20%	Morganite Type SC.DR/SL 3/4
RV10	20k	20%	" " "
RV11	1k	10% W-W	Reliance Type WL/35/PC
RV12	1k	10% W-W	" " "
RV13	25k		Plessey Type E
RV14	10k		" " "
RV15	500	10% W-W	Reliance Type WL35
RV16	500	10% W-W	Reliance Type WL/35/PC
RV17	500	10% W-W	" " "
RV18	100	5% W-W	Reliance Type WL18 P.C.

Capacitors

C1	1592Hz 1000Hz	13,250p 21,000p	1%	200V	Johnson & Matthey Type C33W
C2	1592Hz 1000Hz	6,660p 10,660p	0.5%	350V 200V	Johnson & Matthey Type C33W
C3		700p	10%	125V	GEC Type PF
C4		400µ	+50% -20%	15V	Waycom Printilyt
C5		50µ	+50% -10%	6V	Mullard C426AR/C50
C6		400µ	+50% -20%	15	Waycom Printilyt
C7		400µ	+50 -20%	15	Waycom Printilyt

Cct. Ref	Description			Style or Supplier & Type
C8	2n	10%	150V	GEC Type PFT
C9	25p			Wayne Kerr Type ST25 (C Standard)
C10	10p	±1pF	350V	Lemco Type 1106R
C11	10p	±1pF	350V	Lemco Type 1106R
C12	2.75-15p	Variable		Erie Type 3116C
C13	400µ	+100 -20%	15V	Wima Printilyt
C14	10µ	+50 -10%	15V	Mullard C426/AR/E10
C15	0.1µ	2%	125V	GEC Type PF
C16	Not Used			
C17	10µ	+50% -10%	15V	Mullard C426/AR/E10
C18	250µ	+50% -10%	16V	Mullard C437/AR/E250
C19	400µ	+100% -20%	15V	Wima Printilyt
C20	1000p	2%	125V	GEC Type PF
C21	400µ	+100% -20%	15V	Wima Printilyt
C22	2000p	2%	125V	GEC Type PF
C23	2000p	2%	125V	"
C24	100p	2%	125V	"
C25	400µ	+100% -20%	15V	Wima Printilyt
C26	100µ	+100% -20%	15V	Plessey Type CE121S
C27	5000p	2%	125V	GEC Type PF
C28	1µ	+100% -20%	25V	T.C.C. Type CE-2H
C29	100p	2%	125V	G.E.C. Type PF
C30	0.01µ	2%	125V	G.E.C. Type PF
C31	5000p	2%	125V	G.E.C. Type PF
C32	400µ	+100% -20%	15V	Wima Printilyt
C33	64µ	+50% -10%	15V	Mullard C426/AR/D64
C34	0.25µ	20%	150V	G.E.C. Type PFT
C35	0.25µ	20%	150V	G.E.C. Type PFT
C36	0.25µ	20%	150V	G.E.C. Type PFT
C37	0.25µ	20%	150V	" "
C38	1µ	+100% -20%	60V	Wima Type MKS
C39	10µ	+50% -20%	6V	Wima Printilyt
C40.	16µ	+100% -20%	15V	Plessey Type CE1361

Cct. Ref	Description			Style or Supplier & Type
C41	16µ	+100% -20%	15V	Plessey Type CE1361
C42	6.4µ	+50% -10%	25V	Mullard Type C426/AR/F6.4
C43	6.4µ	+50% -10%	25V	Mullard Type C426/AR/F6.4
C44	1µ	+100% -20%	25V	T.C.C. Type CE-2H
C45	1000µ	+50% -10%	6.4V	Mullard Type C437/AR/C100
C46	5µ	+100% -20%	15V	Plessey Type CE87
C47	5µ	+100% -20%	15V	" " "
C48	0.1µ	2%	125V	G.E.C. Type PF
C49	5µ	+100% -20%	15V	Plessey Type CE87
C50	250µ	+50% -10%	16V	Mullard C437/AR/E250
C51	6800p	20%	150V	G.E.C. Type PFT
C52	100µ	+100 -20	15V	Plessey Type CE1218
C53	0.5µ	20%	150V	G.E.C. Type PFT
C54	2000p	2%	125V	G.E.C. Type PF
C55	2000p	2%	125V	G.E.C. Type PF
C56	500p	2%	125V	G.E.C. Type PF
C57	1200p	2%	125V	G.E.C. Type PF
C58	10µ	+50% -20%	6V	Wima Printilyt
C59	0.01µ	10%	150V	G.E.C. Type PFT
C60*	3-30p	Variable		Mullard Type 7876
	* When fitted			
C61*	A.I.C.	±5%	200V	Lemco Type 1106R SW. Value selected on test from 20, 30, 39 or 50pF.
C62	0.1µ		50V	T.C.C. Type CE68DG
C63	400µ	+100% -20%	15V	Wima Printilyt
C64	200µ	+100% -20%	30V	" "
C65	25µ	+50% -10%	25V	Mullard Type C426/AR/F25
C66 C67	16+16µ	+50% -20%	350V	Hunts Type JF413T
C68	Not Used			
C69	5000µ	+100% -20	12V	Plessey Type CE1203
C70	Not Used			

Cct. Ref	Description			Style or Supplier & Type
C71	Not Used			
C72	2000p	2%	125V	G. E. C. Type PF
C73, C74, C75	1592Hz 6.28n 1000Hz 10n	1%	33V	Waycom Type MIAL 613
C76	1592Hz 3.14n 1000Hz 5.0n	1%	33V	Waycom Type MIAL 613
C77	400µ	+100% -20%	15V	Wima Printilyt
C78	250µ	+50% -10%	16V	Mullard Type C437/AR/E250
C79	400µ	+100% -20%	15V	Wima Printilyt
C80	400µ	+50% -20%	15V	Wima Printilyt
C81	1592Hz 4.7n 1000Hz 10n	±5%	160V	Waycom Tropyfol F
C82	47n	5%	160V	" " " (1592Hz only)
C83	33n	5%	160V	" " " (1000Hz only)

Diodes

Cct. Ref	Type	Supplier
MR1	BYX10	Mullard
MR2	1S2051A	Texas
MR3	OA91	Mullard
MR4	OA200	Mullard
MR5	OA200	Mullard
MR6	OA200	Mullard
MR7	OA200	"
MR8	OA202	"
MR9	OA202	"
MR10	OA202	"
MR11	OA202	"
MR12	OA202	"
MR13	OA202	"
MR14	OA202	"
MR15	OA202	"
MR16	1S020	Texas
MR17	1S020	"
MR18	1S020	"
MR19	1S020	"
MR20	OA200	Mullard
MR21	OA200	"

Transistors

Cct. Ref	Type	Supplier
VT1	40232	R. C. A.
VT2	40332	R. C. A.
VT3	BC109	Mullard
VT4	BC109	"
VT5	40231	R. C. A.
VT6	40232	R. C. A.
VT7	40232	"
VT8	BC109	Mullard
VT9	BC109	"
VT10	BC109	"
VT11	BC109	"
VT12	40231	R. C. A. (Mullard BC108 or 2N706 can be used)
VT13	BC109	Mullard
VT14	BC109	"
VT15	C111	Fairchild
VT16	C111	Fairchild
VT17	2G374	Texas
VT18	2G374	"
VT19	2G374	"
VT20	2G374	"
VT21	40319	R. C. A. (or Mullard BCY32)
VT22	BC109	Mullard
VT23	BC109	"
VT24	40319	R. C. A. (or Mullard BCY32)
VT25	2N3053	"
VT26	40232	R. C. A.
VT27	BC109	Mullard
VT28	BC109	"
VT29	BC109	"

Miscellaneous

TH1	R14	S. T. C. Thermistor
N1-N4 N8-N11	3L	Hivac Neon Lamp
N5-N7 N12-N14	GL12	Philips Neon Lamp
V1-V8	GR10M GN4	Ericsson Alternatives. Digital S. T. C. Indicator Tubes
FS1	250mA 'Slow Blow'	Beswick Type TDC134

Range switch drive belt: Reliance Gear Co. Ref. No. FA126
C and G Range indicator lamps: Ever Ready CIF 21 6.3V 2W.

MP MASTER
MA35879